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Large-scale bioenergy production from soybeans and switchgrass in Argentina Part A: Potential and economic feasibility for national and international markets

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ABSTRACT

This study focuses on the economic feasibility for large-scale biomass production from soybeans or switchgrass from a region in Argentina. This is determined, firstly, by estimating whether the potential supply of biomass, when food and feed demand are met, is sufficient under different scenarios to 2030. On a national level, switchgrass has a biomass potential of 99×10^6 (1.9 EJ) to 243×10^6 tdm (4.5 EJ)/year depending on the scenario. Soybean (crude vegetable oil content) production for bioenergy has a potential of 7.1×10^6 (0.25 EJ) to 13.8×10^6 tdm (0.5 EJ)/year depending on the scenario. The most suitable region (La Pampa province) to cultivate energy crop production is selected based on a defined set of criteria (available land for biomass production, available potential for both crops, proximity of logistics and limited risk of land use competition). The available potential for bioenergy in La Pampa ranges from 1.2×10^5 to 1.8×10^5 tdm/year for soybean production (based on vegetable oil content) and from 6.3×10^6 to 18.2×10^6 tdm/year for switchgrass production, depending on the scenario. Bioenergy chains for large-scale biomass production for export or for local use are further defined to analyse the economic performance. In this study, switchgrass is converted to pellets for power generation in the Netherlands or for local heating in Argentina. Soybeans are used for biodiesel production for export or for local use. Switchgrass cultivation costs range from 33–91 US$/tdm (1€ = 1.47 US$ based on 19 February 2008). Pellet production costs are 58–143 US$/tdm for local use and 150–296 US$/tdm until delivery at the harbour of Rotterdam. Total conversion costs for electricity in the Netherlands from switchgrass pellets range from 0.06–0.08 US$/kWh. Heating costs in Argentina from switchgrass pellets range from 0.02–0.04 US$/kWh. Soybean cultivation costs range from 182–501 US$/tdm depending on the scenario. Biodiesel production costs are 0.3–1.2 US$/l for local use and 0.5–1.7 US$/l after export to the Netherlands. Key parameters for the economic performance of the bioenergy chains in La Pampa province are transport costs, cultivation costs, pre-processing and conversion costs and costs for fossil fuels and agricultural commodities.

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Abbreviations: ARG, Argentina; BA, Buenos Aires; BB, Bahía Blanca; FCE, Feed Conversion Efficiency; GDP, Gross Domestic Product; MS land, moderately suitable land; mS land, marginally suitable land; NL, the Netherlands; S land, suitable land; PPI, Producer Price Index; ROT, Rotterdam; VS land, very suitable land.

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1. Introduction

Many energy scenarios and policy objectives indicate a growing increase in the production and use of biomass as an energy source [1]. Without further development of biomass energy resources (e.g. through energy crop plantations and better use of residues) and a well functioning biomass market to assure a reliable and lasting supply, the often ambitious targets for bioenergy use may not be met [2].

Several studies [3,4] show that there are some key regions in the world that have a short and long-term underutilized potential for bioenergy production. These regions show a technical potential for using residues as well as possibilities for bioenergy production using dedicated plantations. One of these key regions is the Mercosur which includes Argentina.

On the other hand, there are countries, like the Netherlands, that have insufficient land to meet its projected bioenergy demand. In this case, the development of truly international markets for biomass is essential to meet the country's demands. New trade flows may offer multiple benefits for both exporting and importing countries. For example, exporting countries may gain an interesting source of income and an increase in employment from sustainable biomass production. To be able to realize a well functioning biomass market with a reliable and lasting supply, it is important to determine the economic feasibility of biomass production on the short and longer term in a sustainable manner.

Argentina is in this study chosen as biomass producing country, first, because of its favourable climate and soil conditions for growing biomass. Second, low land and labour costs are beneficial for achieving low bioenergy production costs. In addition, Argentina's existing infrastructure and human resources facilitate the production and transportation of bioenergy. The Netherlands is selected as importing country in this case study. Biomass is the most important source of renewable energy in the Netherlands [5]. A 30% contribution of biomass (around 1000 PJ of primary energy) to the national energy and material supply is expected after 2030 [5], which requires imports from abroad [6].

The study focuses on two different energy crops: soybean and switchgrass. Large-scale cultivation of these crops is based on current and more advanced production technologies. Soybean, as an annual crop, is currently the principal crop and the main export product in Argentina [7]. Several experts in Argentina [8–11] confirm that soybean is one of the more promising crops in Argentina for bioenergy production. In this study, soybeans are converted to biodiesel for export to the Netherlands or for local use. Switchgrass, a C4 perennial grass, is the second energy crop selected for this study and largely unknown in Argentina as energy crop. Switchgrass is mainly used in Argentina for forage production for livestock [12]. The potentially high yields and high contents of lignin and cellulose, generating a high heating value, makes switchgrass attractive for bioenergy production [13]. Combined with the fact that 77% of the agricultural land in Argentina is dedicated to permanent pasture [14], it suggests that this grass can be an interesting option for bioenergy production in Argentina too. In this study, we consider switchgrass conversion to pellets for export and use for power generation in the Netherlands, or for the local market using switchgrass pellets for heating.

The economic feasibility for large-scale export of biomass or biofuels from soybeans or switchgrass from a region in Argentina is determined firstly by estimating whether the potential supply of biomass, when food and feed demand are met, is sufficient under different scenarios. Beside the biomass potential, other factors such as logistics also play a role in the feasibility of large-scale export of biomass pellets or fuel. Therefore, in this study a promising region of Argentina is selected that show the best potentials to develop large-scale biomass production. After the selection of a promising region, the bioenergy chains for large-scale export (and for comparison local use) of the biomass fuels are more precisely defined to allow an investigation of the economic performance. Consequently, the economic feasibility is determined for large-scale biomass production from soybeans and switchgrass in the selected region in Argentina.

2. Key characteristics of Argentina

Argentina is the second largest country of Latin America with a total land area of 273 million hectares. The country is divided into 23 provinces and one autonomous city, the capital city Buenos Aires [15]. The total population of Argentina is around 36 million people (2001), of which almost 90% are living in urban settings. Despite the economic crisis of 2001/2002, Argentina's economy (with a GDP of 182 billion US$ in 2005) is one of the largest in Latin America [16]. While agriculture contributes only 8% to the national GDP in 2007, around 55% of the value from export originates from the agricultural sector [17]. Soybean and soybean derivatives represent the majority (51% in 2003) of the Argentine agricultural export [18].

2.1. Land use characteristics and agriculture in Argentina

Due to a high variety in soils, temperature and rainfall in Argentina, there is a wide variety of eco-regions, each one having its own characteristics in crop suitability [19]. Of the 273 million hectares of land, Argentina has 128 million hectare of agricultural land, of which 99 million are permanent pastures, 28 million are arable land and 1 million are permanent crops [14]. The fertile plains of the centre and the northeast of the country represent the core of Argentina's agricultural production (80% of all agricultural crop production and 75% of the national livestock production takes place in this region). The main agricultural crops in Argentina are soybeans, maize, wheat and sunflower [14]. 90% of the soybean production comes from genetically modified crops [15]. Application of direct seeding and no-till cropping systems has become the dominant production system by 2005. No till farming has reached more than 70% of the extensive agriculture crops [20]. Fertilizer input has increased in recent years, although it is still significantly lower than in North America or Europe, due to the fertility of the agricultural land in Argentina [21]. Currently, the main problems are the high harvest losses [22].

The traditional soybean production areas are located in Las Pampas containing parts of Buenos Aires, Córdoba, Santa Fe and Entre Ríos [23]. In recent years, however, agriculture (primarily soybean production) has extended to less fertile and more remote areas in the northeast and west of Argentina [18]. This trend has driven livestock production into less fertile lands since soybean production generates more income [24]. Soybean production in Argentina increased from 12×10^3 tons in 1995 [14] to 47×10^3 tons in 2006/07 [25].

Livestock production in Argentina is primarily based on a pastoral feeding system with direct grazing from natural grasslands and cultivated pasture [26]. Concentrated feed is added to this diet in short periods of the year only for fattening the animals (feed lot) or when there is a shortage of nutrients coming from the grasslands. Argentina has various agro-ecological livestock regions that differ in their potential of production and quality of forage. For this reason, a distribution of livestock activities over the country can be noticed.

Currently, there are no agricultural subsidies in Argentina, neither at national nor at local level. The export tax for agricultural products is on average around 20% of the export value. The tax is supposed to ensure local food supply and to keep food prices on a stable level [27]. Taxes for soybean products contribute to around 12.5% of the federal government budget of Argentina [18]. Early 2008, export taxes were revised and taxes for soybean increased from 35% to 45% [28]. In Argentina, meat prices are regulated and decoupled from international market prices.

2.2. Energy use in Argentina and the promotion of biomass for renewable energy and biofuels

Argentina uses mainly petroleum products (41%) and natural gas (40%) for its final energy consumption [29]. Natural gas is used primarily by the industrial sector to generate electricity. At a lesser extent, it is used in households. Diesel accounts for the largest percentage of local petroleum demand and is mainly used in the transport sector. The road transport fuels used in Argentina are diesel, petrol and Compressed Natural Gas (CNG). From these three, diesel is the main transport fuel. At present, Argentina is a net natural gas and oil exporter. The energy market in Argentina is still distorted as energy subsidies on electricity and fuel consumption continue to prevail. Combined with a significant lack of investments in the energy sector, and a strong increase in energy demands, this resulted in energy shortages in recent years [27]. Consequently, from 2002 onwards, Argentina had to import diesel and fuel oil [30]. In 2005, 3.1% of the annual diesel consumption was imported [27].

Argentina has a framework that regulates and promotes the production and use of renewable energy. Law 26.190, established in 2007, sets an 8% target for renewable energy consumption in the period of 10 years and mandated the creation of a Trust Fund whose resources will be allocated to pay a premium for electricity produced from renewable sources [31].

The Biofuels Law from 2007 established a 5% mandatory use of biodiesel and bioethanol in all diesel oil and gasoline consumption, beginning January 1, 2010 [30]. Until the beginning of 2008, biodiesel export was taxed with 5% and a 2.5% tax deduction. However, this tax has changed to 20% with a 2.5% tax deduction [32]. Although the difference between the export tax of soybean oil for food and feed on the one hand and biodiesel on the other hand is still attractive for Argentine biodiesel producers, it also shows that export taxes can possibly change drastically having an impact on biodiesel export prices.

To comply with the Biofuels Law, it is estimated that about 700 million liters of biodiesel and 250 million liters of ethanol will be needed in 2010 [30]. End of 2007, there were 9 biodiesel companies having a total technical production capacity of 585.000 tons, from which only 180.000 tons was effectively used. It is expected that this number will increase to a production capacity of 1.424.700 tons end of 2008, realised by 18 different companies [33]. In February 2008, Argentina exported 47.634 tons of biodiesel from which 77% was exported to the USA, 13% to the Netherlands and 10% to France [32]. Soybean oil is currently the main feedstock for biodiesel production in Argentina. Beside, there are several small plants using recycled vegetable oil, sunflower and rapeseed oil. Corn, sugar cane and molasses are currently the main feedstocks for ethanol production in Argentina and there is interest in using sorghum [30]. There are 15–16 small producers of bioethanol serving the beverage, food and pharmaceutical industry in Argentina.

3. Assessment of the potential of biomass for energy production

The potential of biomass for energy production in Argentina is assessed by investigating the availability of land. Next, the potential is assessed on a provincial level in Argentina for various land use scenarios. Soybeans and switchgrass are the energy crops investigated.

3.1. Scenario development to assess the national and provincial biomass potential for energy

In this study, a scenario is used as an imagined possible future situation placed in a defined time set. The scenarios used to assess the national biomass for energy potential characterize drivers in Argentina related to agriculture, energy and land use. The drivers are translated into quantitative parameters (see Table 1) and used in the assessment [34]. They are also used to evaluate the economic performance. The time frame considered is 2030. Three main trends can be determined, based on different levels of production and trade, productivity and environmental awareness, reflecting different story lines. The dimension 'production and trade' reflects the trends in trade balance, domestic consumption and national welfare for different scenarios.

Estimations for the current situation (CUR) present the biomass potential and economic performance of the bioenergy chains on the short term. Scenario A reflects the baseline scenario for the development of the economy. Scenario B and C are characterized by a stronger rise in economic development. Between them, scenario C is more export oriented, while scenario B is more environmental friendly and oriented on the domestic market.

Table 1
Input parameters for assessment of potential for biomass for energy in Argentina for current situation (CUR) and for scenarios, A, B and C in year 2015 and 2030.

Parameter	CUR, Scenario A	Scenario B	Scenario C
GDP (in US$/capita)	CUR: 1997–99: 8085, 2002: 2711 Scenario A: 2015: 3882, 2030: 6503	Rise in economy 2015: 4571, 2030: 8351	Strong rise in economy 2015: 4995, 2030: 10610
GDP growth rate in % per year	1997–99 to 2015: 2.8%, 2015 to 2030: 3.5%	1997–99 to 2015: 4.1%, 2015 to 2030: 4.1%	1997–99 to 2015: 5.15%, 2015 to 2030: 5.15%
Population growth in % per year	Scenario A: 1997–99 to 2015: 1.3%, 2015 to 2030: 0.9%	Rise in economy results in slowing down population growth. 1997–99 to 2015: 0.86%, 2015 – 2030: 0.49%	Strong rise in economy results in strong slowing down population growth. 1997–99 to 2015: 0.56%, 2015 – 2030: 0.3%
Population in 10^7 inhabitants	CUR: 1997–1999: 3.72, 2002: 3.99 Scenario A: 2015: 4.72, 2030: 5.39	2015: 4.46, 2030: 4.79	2015: 4.29, 2030: 4.48
Total food consumption in 1000 tonnes	CUR: 1997–1999: 31616, 2002: 28659 Scenario A: 2015: 36647, 2030: 44473	2015: 37306, 2030: 41725	2015: 38068, 2030: 41600
Food distribution pattern	Based on FAO outlook Argentina [35]	Food distribution pattern 2030 is based on distribution pattern Argentina 1997–1998 [35] 2015: 3013 cal/cap/day, 2030: 3032 cal/cap/day	Food distribution pattern is based on pattern USA (2003) for year 2030 [35] 2015: 3185 cal/cap/day 2030: 3213 cal/cap/day
Total domestic use excluding feed (other uses) in 1000 tonnes	CUR: 1997–1999: 78743, 2002: 80186 Scenario A: Rise of Other Uses in line with the growth of total food consumption in 2002–2015 and for 2015–2030. 2015: 107393, 2030: 146308	Growth in line with the growth of total food consumption. Rise of high value agricultural products leads to 2.5% growth in food manufacturing in 2002–2015 and in 2015–2030 compared to scenario A. 2015: 111788, 2030: 131944	Growth in line with growth of total food consumption. Strong rise of high value agricultural products leads to 5% growth in food manufacturing in 2002–2015 and in 2015–2030 compared to scenario A. 2015: 116852, 2030: 126539
Net trade in 1000 tonnes	CUR: 1997–1999: 33550, 2002: 37072, Scenario A: 2015: 50007, 2030: 64376	Trade scenario is based on data main agricultural products [39] 2015: 53575, 2030: 74962	2015: 56125, 2030: 75050
Main agricultural export crops in %	CUR: 97–99: cereals (63%), oil crops and vegetable oils (20%) 2015: cereals (57%), oil crops and vegetable oils (30%), meat and milk (4%) 2030: cereals (57%), oil crops and vegetable oils (30%), meat and milk (4%)	Stronger increase in trade of meat and egg products. 2015: cereals (53%), oil crops and vegetable oils (23%), meat and milk (4%) 2030: cereals (56%), oil crops and vegetable oils (22%), meat and milk (5%)	Strong increase of trade in high value products as meat, milk, fruit, vegetables and vegetable oils. Decrease in trade cereals. 2015: cereals (46%), oil crops and vegetable oils (24%), meat and milk (8%) 2030: cereals (45%), oil crops and vegetable oils (20%), meat and milk (14%)
Agricultural management system	Intermediate input system	Mixed input system	High Input system
Yield increase crops In %	2015: 5% compared to current situation 2030: 10% compared to current situation	2015: 5% compared to current situation 2030: 10% compared to 2015	2015: 5% compared to current situation 2030: 15% compared to 2015.
Land suitability natural grasslands	15% of natural grasslands are used for feed production, 2% of natural grasslands can be converted to agricultural production Natural grasslands for fodder production: based on current yield levels (low-input)	15% of natural grasslands are used for feed production,, 4% of natural grasslands can be converted to agricultural production (mS land) Natural grasslands for fodder production: Yield levels are 5% higher than current yield levels	15% of natural grasslands are used for feed production,, 6% of natural grasslands can be converted to agricultural production (mS land) Natural grasslands for fodder production: Yield levels are 10% higher than current yield levels
Feed Conversion Efficiency (FCE)	CUR: Based on data Latin America 1995 [36] 2030: Based on data Latin America from [36] Pastoral livestock production continuous to be important.	2030: Medium input livestock production system: increase of mixed/landless production with co-existence of pastoral production. FCE: Average between scenario A and C	2030: Highly intensified livestock management system with high dominance of mixed/landless production system. Based on data for USA from [36]
Division feed crops	Based on data Latin America from [36]	Average between scenario A and C	Based on data USA from [36]

3.2. Methodology national and provincial biomass potential assessment

A bottom-up approach, based on the studies from [4,34], is used to assess the biomass potential for energy on a national and provincial level in Argentina. For each scenario, the domestic demand for food and feed is fulfilled. A certain area of agricultural land will be needed to meet this demand. The size of this area depends not only on the demand for food and feed, but also on the productivity of the agricultural production system and the allocation procedures. The allocation procedures define the land most suitable for each crop based on individual requirements. This means that crop preferences of farmers based on (inter-) national price tendencies are not taken into account. The current land, excluding forest areas and protected areas, minus the required land for food, feed and livestock production gives the surplus land for biomass production that can be available

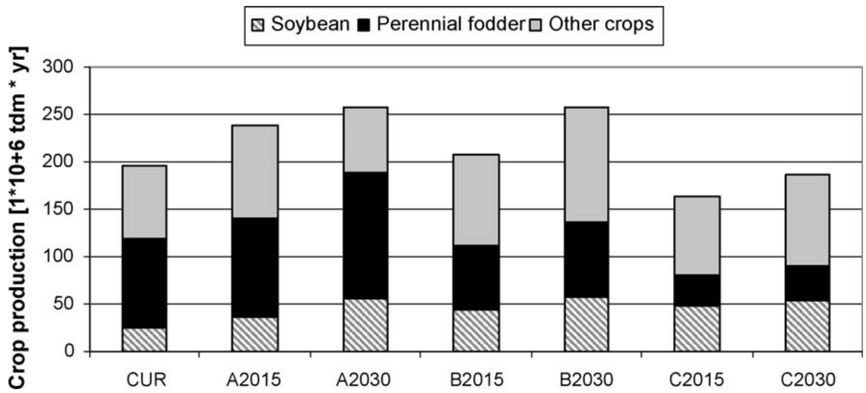

Fig. 1. Estimated crop production in 1×10^6 t dm/year (minus required feed from natural grasslands and required production for tomatoes, onions and other vegetables) on country level for current situation and for scenarios A, B and C for the years 2015 and 2030.

for energy crop cultivation. The amount of total biomass from this land is calculated by multiplying the available land (in ha) with the productivity (t/ha) for energy crops on this land.

Soybean generates crude oil for biodiesel (20% incl. waste) and pellets for feed (80%). Only the crude soybean oil can be used for bioenergy production. An extra allocation step is therefore made to calculate the usable biomass potential from crude soybean oil for bioenergy. The possibility to use the generated soybean pellets again as input in the model to meet required feed demand, providing in return extra land for bioenergy production, is analyzed.

Databases on food and livestock demand in Argentina are available from [12,14,25,35–40]. In our assessment, it is assumed that forest production and forest land remains constant over time. Consequently, changes in the demand of forest products are not included in the assessment.

Databases on the productivity and land suitability of individual crops for an intermediate, mixed input and high input agricultural production system (all rain-fed) are available from [41] on country level and converted to provincial level with data from [25]. The assumption behind is that the current production of an individual crop takes place on the land that is most suitable for this crop. A description of the selected agricultural production systems is presented in [41,42] and summarized here:

- Intermediate production system, rain-fed: some use of fertilizers, pesticides, improved seeds or breeds, animal health care and mechanical tools.
- High input production system, rain-fed: full use of all required inputs and management practices as in advanced commercial farming at present found in the USA and the EU.
- Mixed input production system, rain-fed: high level of technology on very suitable to suitable soils, medium level on moderately suitable areas and low level on moderately to marginally suitable areas.

In total, in Argentina more suitable land for agricultural production is available for the high input and mixed input system than for the intermediate production system according to data from [41]. It is assumed that the current agricultural production corresponds to the intermediate production system. Note that the biomass potential calculated in this study does not include wood from surplus production forest, agricultural and forest residues.

Table 2
Available land for bioenergy production from soybeans in 1000 ha on national and on provincial level for current situation (CUR) and for scenarios A, B, and C for year 2015 and 2030.

	CUR	A2015	A2030	B2015	B2030	C2015	C2030
Total land	33338	27993	17995	32073	28357	24181	25019
Buenos Aires	10505	9506	5468	12613	11490	7775	7940
Catamarca	126	118	92	132	134	87	89
Córdoba	9599	8490	5263	10107	8370	7960	8066
Corrientes	24	23	18	25	26	17	17
Chaco	1200	718	626	648	643	672	895
Chubut	0	0	0	0	0	0	0
Entre Ríos	2291	2007	1239	1093	1786	1711	1742
Formosa	28	26	21	29	29	19	19
Jujuy	4	4	2	5	5	3	3
La Pampa	399	374	289	417	424	275	282
La Rioja	0	0	0	0	0	0	0
Mendoza	0	0	0	0	0	0	0
Misiones	10	9	7	10	11	7	7
Neuquén	0	0	0	0	0	0	0
Río Negro	0	0	0	0	0	0	0
Salta	971	943	636	617	892	781	787
San Juan	0	0	0	0	0	0	0
San Luis	189	177	137	197	200	130	133
Santa Cruz	0	0	0	0	0	0	0
Santa Fe	6026	4385	3121	4961	3345	3424	3551
Santiago del Estero	1305	803	759	733	615	938	955
Tierra del Fuego	0	0	0	0	0	0	0
Tucumán	661	408	317	487	388	381	532

Table 3
Available land for bioenergy production from switchgrass in 1000 ha on provincial level for current situation and for scenarios A, B and C for 2015 and 2030.

	CUR	A2015	A2030	B2015	B2030	C2015	C2030
Total land	15851	15038	10311	16648	15917	17046	17413
Buenos Aires	4385	4231	3116	5197	5098	5638	5632
Catamarca	52	52	52	42	42	52	52
Córdoba	3251	3157	1400	3685	3651	3895	3894
Corrientes	2570	2552	2361	2642	2648	2537	2537
Chaco	515	193	192	179	174	204	464
Chubut	7	7	7	6	6	7	7
Entre Ríos	771	753	310	273	846	878	879
Formosa	23	23	23	39	38	54	54
Jujuy	40	40	40	32	32	41	41
La Pampa	837	791	650	1121	1061	1270	1269
La Rioja	21	21	21	17	17	21	21
Mendoza	85	85	85	69	69	86	86
Misiones	155	151	135	177	175	186	186
Neuquén	5	5	5	4	4	5	5
Río Negro	35	34	35	28	28	35	35
Salta	207	207	207	167	167	209	209
San Juan	25	25	25	20	20	25	25
San Luis	307	306	307	248	248	304	304
Santa Cruz	3	3	3	3	3	3	3
Santa Fe	2095	1943	874	2326	1217	1127	1240
Santiago del Estero	302	302	302	244	244	306	306
Tierra del Fuego	0	0	0	0	0	0	0
Tucumán	160	160	160	129	129	162	162

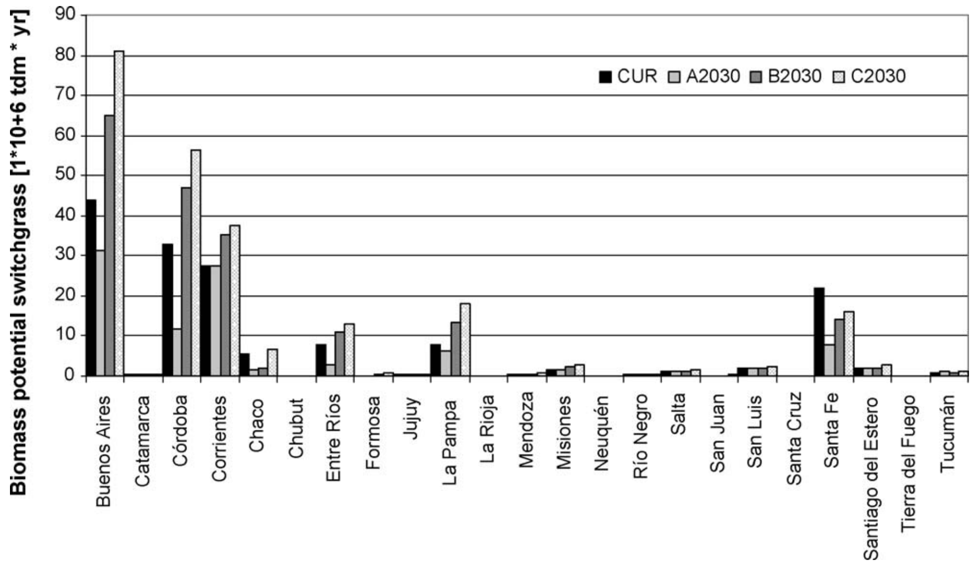

Fig. 2. Biomass potential for energy production in 1×10^6 tdm/year from switchgrass on provincial level for current situation (CUR) and for scenarios A, B and C to 2030.

3.3. Results required food and feed production and land availability for biomass for energy

The required food and feed production is calculated for each scenario on a national and provincial level. Some results are shown in Fig. 1. Scenario (A2030) and (B2030) have higher levels of required crop production due to higher demands for food consumption and feed and lower levels of the Feed Conversion Efficiency (FCE).

The amount of land that is available for bioenergy production, subdivided to different land suitability classes, is calculated on provincial level by allocation (see also Section 3.2). Table 2 shows the sum of the total available land for bioenergy production from soybean. Limited amounts of land for soybean production are available in scenario (A2030). Table 3 shows the sum of total available land for bioenergy production from switchgrass. Again, a limited availability of land for bioenergy production is found in scenario (A2030).

Soybean pellets (80% of whole crop) are currently largely used for export in Argentina. The pellets, produced on land for soybeans for bioenergy production, can also be used to meet national feed demand. This generates consequently extra land for bioenergy production. The extent of extra available land is calculated for scenario C2030, characterised by a high-input production system. When the pellets are used to replace other feed crops, an extra 66×10^5 ha becomes available, from which 65×10^5 ha is very suitable (VS) land. Only limited amounts of this land (5000 ha of S land) are suitable for soybean production and the remaining extra available land can be used for other purposes. In case the pellets are used to replace fodder from grasslands, an extra 21×10^5 ha becomes available from which 88×10^4 ha of S land is suitable for soybean production.

3.4. Results national and provincial assessment of the potential for biomass for energy

For switchgrass, the total potential of biomass for energy production on a national level is, depending on the scenario, 995×10^5 to 243×10^6 tdm/year. Fig. 2 shows the estimated switchgrass production for bioenergy production on surplus land

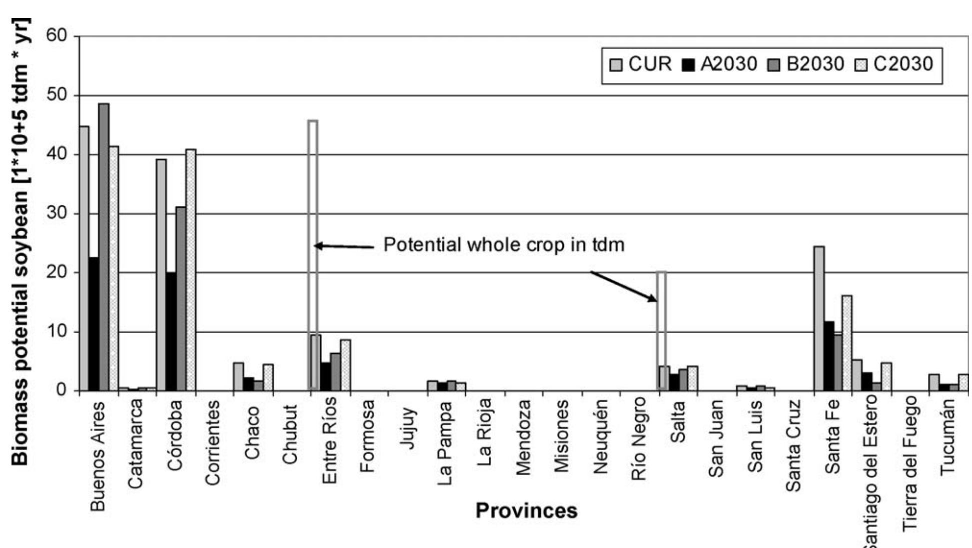

Fig. 3. Biomass potential from energy production from crude oil production from soybeans (20% of whole crop) in $1 \times 10^{+5}$ tdm/year on provincial level for current situation and for scenarios A, B and C to 2030.

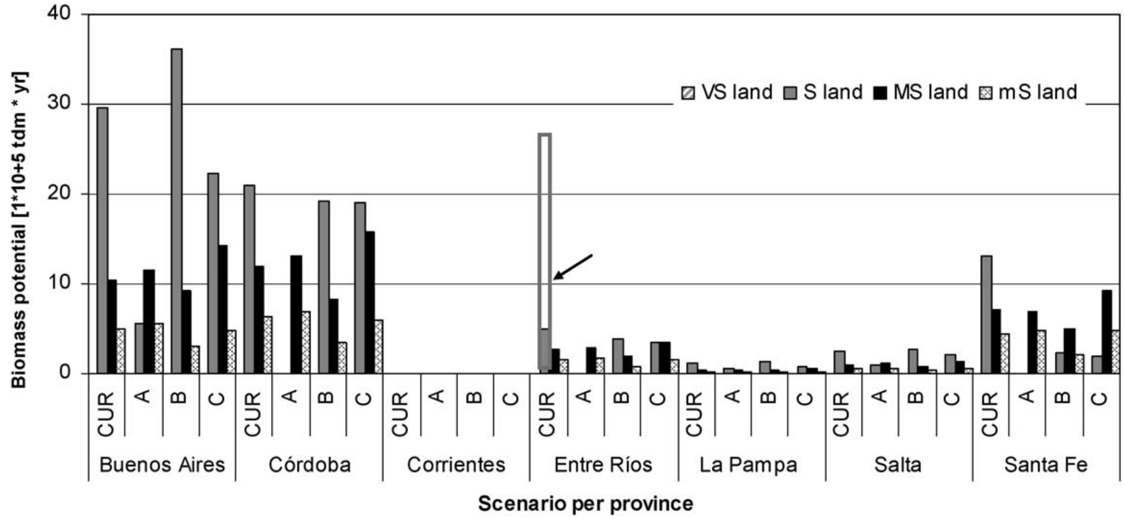

Fig. 4. Biomass potential from energy production from crude oil production from soybeans in 1×10^5 tdm/year for provinces with highest potential, per land suitability type for current situation and for scenarios A, B and C to 2030.

for each selected scenario. The five provinces with the highest potential of biomass for energy from switchgrass under different scenarios are: Buenos Aires, Córdoba, Corrientes, La Pampa and Sante Fe (Fig. 3).

For soybean, the total potential of biomass for energy production on a national level is, depending on the scenario, 353×10^5 to 690×10^5 tdm/year for the whole crop. This generates yearly 706×10^4 to 138×10^5 tons of crude soybean oil. When the soybean pellets on land for bioenergy production are used to replace fodder from grasslands (see Section 3.3), an additional 542×10^3 tons of crude soybean oil in scenario (C2030) is produced. Only 10×10^3 tons of extra crude soybean oil is produced when the pellets replace other feed crops.

Fig. 4 shows the estimated crude soybean oil production from soybeans for bioenergy production on surplus land for each selected scenario. The five provinces with the highest biomass potential from soybeans under different scenarios are: Buenos Aires, Córdoba, Entre Ríos, Salta and Santa Fe.

Figs. 4 and 5 show the biomass potential for soybean and switchgrass, subdivided to land suitability type, from surplus land available in the identified provinces. The figures show that most biomass production for bioenergy comes from a combination of S and MS surplus land for both crops. It is concluded that the available potential for biomass energy production is substantially higher for switchgrass production than for soybean production.

4. Defining the region for large-scale bioenergy production in Argentina

The selection of a suitable region for large-scale bioenergy production in Argentina is based on the following set of criteria:

(1) Sufficient land availability for biomass for bioenergy production under different scenarios.
(2) Production potential for both selected energy crops in the defined region.
(3) Limited risk for competition between land for bioenergy production and land for food or feed.
(4) Proximity of logistical infrastructure.

After identification of a suitable region, the available area to produce biomass can be further characterized.

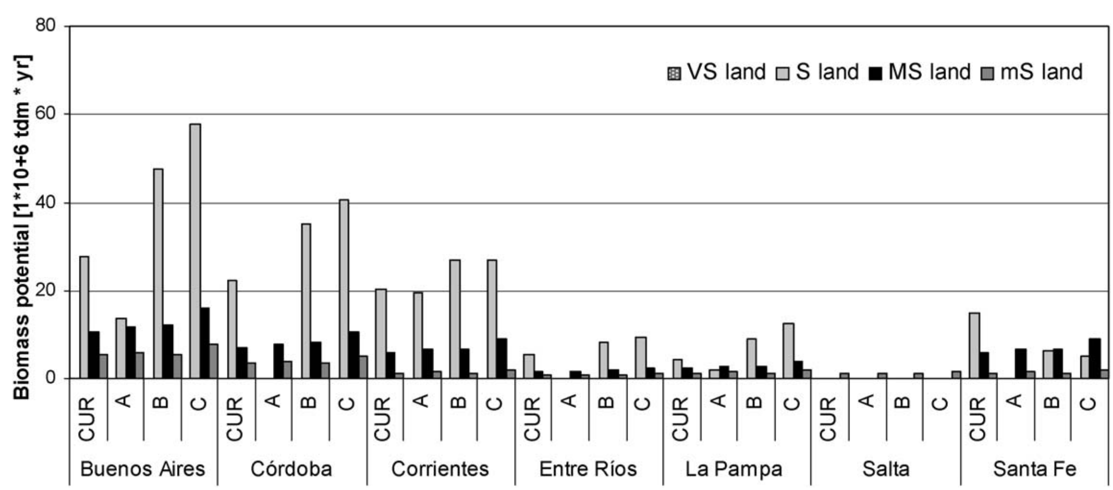

Fig. 5. Biomass potential for energy production from switchgrass in 1×10^6 tdm/year for provinces with highest potential, per land suitability type for current situation and for scenarios A, B and C to 2030.

4.1. Selection of suitable region for large-scale bioenergy production in Argentina

Based on the results in 3.3 and 3.4, seven provinces have been identified showing sufficient surplus land and a good potential for bioenergy production from both switchgrass and soybean production for the selected scenarios. These provinces are Buenos Aires, Córdoba, Corrientes, Entre Rìos, La Pampa, Salta and Santa Fe. Buenos Aires and Córdoba show the best results for both soybean and switchgrass production. Corrientes, Santa Fe and La Pampa show good results for switchgrass production for the scenarios, while Salta and Entre Rìos show, compared to the other provinces, a lower potential. Entre Rìos, Salta and Santa Fe show a good biomass potential for soybean production, while La Pampa and Corrientes show compared to the other provinces, lower outcomes.

To be able to analyze the economic performance of the selected energy crops, the second criterion requires that both soybean and switchgrass can grow and have a production potential in the selected region. Data from [25] show that current soybean production in Corrientes is limited, while the current perennial fodder production is limited to zero in Salta.

The main eco-regions dominating the provinces with the best biomass potential results are the Pampas, the Espinal and Chaco Seco eco-region, each one having its own ecological characteristics [43]. The Pampas eco-region (occupying the plains in the east of Argentina) is the most fertile region in Argentina and can be identified as most suitable for soybean production because of its optimal conditions (between 20–33 °C and an average rainfall between 600–1500 mm [44]. Switchgrass can grow on a wider variety of land types. Because of competition of land, less fertile eco-regions (as the Chaco and Espinal eco-regions) are preferred for bioenergy production. Growing switchgrass for bioenergy in the Espinal eco-region or in the erosion sensitive sandy areas in the Las Pampas eco-region is also recommended by [45]. To select a suitable region for biomass for energy production, an area on the fringe of the Pampas and Espinal/Chaco eco-region would be most preferred for both crops.

Avoidance of competition in land use between land used for bioenergy production and land used for food or feed is an important criterion for sustainable large-scale biomass production, although less relevant for soybeans providing pellets for feed as one of its outputs. An indicator for competition in land use is its price. In Argentina, there is a large variation in land price within a province depending on the sub-region and the indicated land use [46]. Another indicator for competition in land use is the

Fig. 6. Location of main harbour areas and location of existing and planned processing plants in Argentina related to the soybean and switchgrass bioenergy chain.

Table 4
Performance of seven provinces, selected based on their high biomass potential for switchgrass and soybean production for bioenergy in the short and long term, on defined set of four criteria (as listed below) with as objective to select a promising region for biomass for energy in Argentina (++ is good, +is medium, 0 is low performance).

Criteria and performance indicators	Provinces						
	Buenos Aires	Córdoba	Corrientes	Entre Rìos	La Pampa	Salta	Santa Fe
(1) Sufficient land available for bioenergy production							
Biomass potential from soybean	++	++	0	+	+	+	+
Biomass potential from perennial grass	++	++/+	++/+	+	+	0	+
(2) Production potential for selected energy crops							
Current soybean production in the province	++	++	0	+	+	+	+
Current perennial grass production in the province	+	+	+	+	+	0	+
(3) Limited risk for competition in land use							
Availability of Las Pampas/Espinal eco-region	0	++	0	++	++	0	++
Land price	0	++ (North)	+	+ (North)	++	++	++ (North)
Population density in the area	0 (North-east)	0 (East)	++	+	++	++	0 (South)
Recent expansion soybean production	++	++	+	0	+	0/-	++
(4) Proximity of logistical infrastructure							
River infrastructure	++	+	++	++	+	0	++
Proximity harbour	++	+	+	++	+	0	++
Railway network	++	++	+	+	+	+	++
Road infrastructure and distance to harbour	++	+	+	++	+	0	+
Availability pelletizing plant or in planning	0	0	++	+	0	0	0
Availability crushing facility	0	0	0	++	0	0	++
Availability biodiesel plant or in planning	++	0	0	0	0	0	++

Table 5
Amount of available land in 1000 ha for bioenergy production from soybean and from switchgrass in La Pampa province per land suitability type[a] for current situation and for scenarios A, B and C for the year 2015 and 2030.

Scenarios	Soybean production				Switchgrass production			
	VS	S	MS	mS	VS	S	MS	mS
CUR	0	236	103	61	0	347	278	212
A2015	0	211	103	61	0	301	278	212
A2030	0	125	103	61	0	161	278	212
B2015	0	201	142	74	0	690	260	171
B2030	0	238	122	64	0	630	260	171
C2015	0	117	114	44	0	757	299	214
C2030	0	122	115	45	0	756	299	214

[a] VS = very suitable land, S = suitable land, MS = moderately suitable land, mS = marginally suitable land.

population density, which is highest in the urban centres of Buenos Aires, Córdoba, Rosario and Mendoza where 90% of the population lives.

Finally, the economic feasibility of large-scale biomass production for export is related to the proximity of infrastructure and other logistical facilities like harbours. Road and railway infrastructure is available in all selected provinces [47,48] although there is a difference in the density of these networks. Important for railway and truck transport is the required transport distance of the produced biomass to the nearest harbour or processing facility. The location (approximately, on provincial level) of available and planned processing units in Argentina such as crushing facilities, biodiesel plants and pelleting plants, are indicated in Fig. 6.

Table 4 gives an overview of the performance of the selected provinces in relation to all criteria and indicators identified. From this table, it is concluded that the most suitable region for biomass production would be the north-east of La Pampa province/south of Cordoba, bordering the north-west of Buenos Aires and south-east of San Luis. In our regional analysis, we will focus on La Pampa province.

4.2. Socio-economic characteristics of La Pampa province

The province La Pampa has a surface area of 143.440 km^2. Its capital is Santa Rosa [49]. The average population density is 2.27 habitants/km^2 in 2006. The eastern part of the province is more densely populated (around 3 habitants/km^2). The urban population is 81.3% in 2001 [50].

4.2.1. Land use characteristics of La Pampa province

The eastern part of the province is dominated by crop production. More to the west, land is mainly used for grazing areas for cattle, which are more extensively managed to the west [51]. Important cereals in the province are wheat and maize. Sunflower and soybean are dominating oil crops. The seeded area for soybean cultivation in the province is still relatively small, although the area increased 373% from 1993 to 2001. In the same period, cattle production for beef decreased while dairy production (being more intensive) increased [51]. There is no or very limited irrigation in the selected region. The reason is that deeper soils contain salt water causing salinization of soils when pumped up [52]. The contribution of the agricultural sector to total gross domestic product of the province decreased from 26% in 1993 to 19% in 2006. The livestock sector contributed 65% to the gross domestic product of the agricultural sector in 1993 compared to 54% in 2006 [49]. Most of the agricultural land in La Pampa province is privately owned [52]. The number of agricultural units has decreased with 10% between 1998 and 2002. 77% of the exploitations have an area of 50–5000 ha. In the period 1998–2002, the number of agricultural units with a small area size decreased while the number of units with a large area size increased [51].

4.2.2. Specifying the biomass for energy potential results for La Pampa province

The assessment of the biomass for energy potential shows the amount of land that is available for soybean and switchgrass production (in 1000 ha) for various scenarios (see Table 5). For both crops and for all scenarios, no very suitable (VS) land is available for bioenergy production. Depending on the scenario, switchgrass has a regional potential of 627 $\times$ 10^4 (A2030) to 182 $\times$ 10^5 (C2030) tdm/year. The potential for soybeans (whole crop) in the selected region ranges from 615 $\times$ 10^3 (C2015) to 893 $\times$ 10^3 (B2030) tdm/year in La Pampa province for the various scenarios, generating yearly 123 $\times$ 10^3 to 179 $\times$ 10^3 tons of crude soybean oil.

Maps about the current potential of crop production in La Pampa province [20,53] show that soybean production is limited to the eastern part of the province. The VS land in the east of the province changes over short distance to less suitable land in the west of the province. The suitable land for extensive grazing and grassland covers a larger area in La Pampa province. This shows that switchgrass can be grown on land where soybean production is not feasible. It must be noted that, according to the methodology used [41], the land suitability types of various crops are not located per definition on the same geographical location. In other words (as an example) MS land for soybean production can still be S land for switchgrass production.

Soybean yields used in the assessment of the biomass for energy potential for the scenarios till 2030 are shown in Fig. 7. An average yield level of 2.8 t/ha for S land [41] is assumed for the current situation. The national historical trend in soybean yield [25] is in line with scenario C. Soybean yields vary, however,

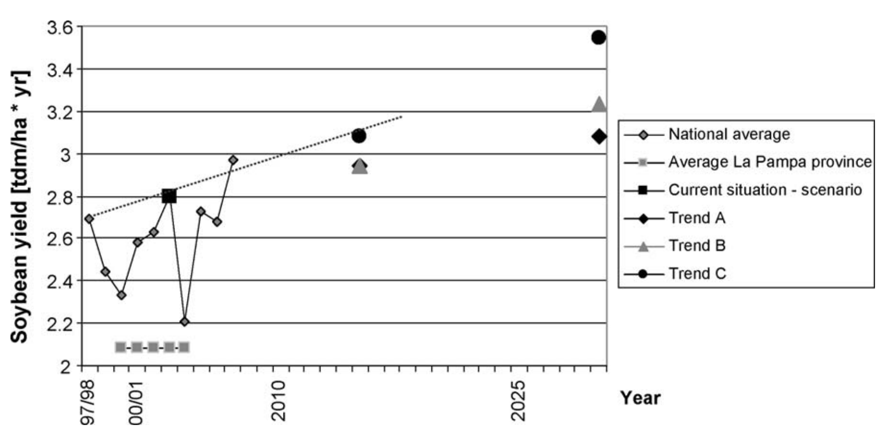

Fig. 7. Historical yields in La Pampa province and on national level for soybean production for bioenergy in tdm/ha/year, based on S land, and related yield expectations in scenarios A, B and C to 2030.

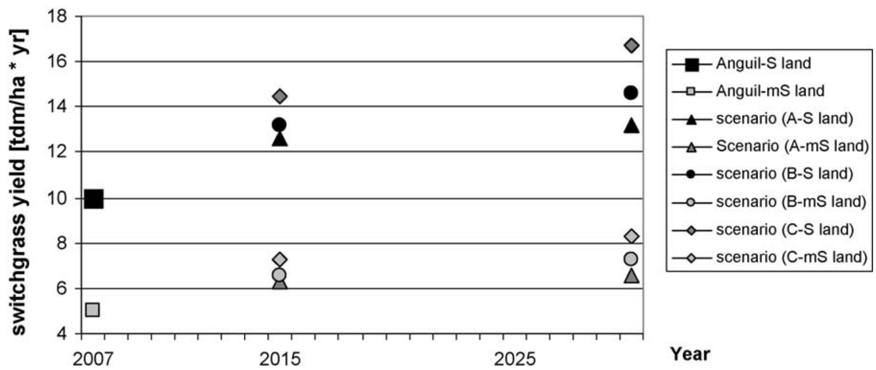

Fig. 8. Current switchgrass yields for biomass energy potential assessment in tdm/ha/year for mS and S land, measured in Anguil (La Pampa province) and yield expectations in scenarios A, B and C to 2030.

strongly within the country and the average soybean yield in La Pampa province (2.08 t/ha) is currently lower than the national average [25,49]. A 50–70% yield increase to 2030 in the province is therefore required to meet the yield levels in scenario (C2030), when looking at the yield levels for S land, which is equivalent to an annual increase of 40–60 kg/ha. Scenario A requires the lowest yield increase while scenario C requires the highest yield increase till 2030.

Data about current switchgrass yield are more limited available for Argentina. An estimated yield level for switchgrass of 10 tdm/ha/year is given by [54] for the area around Anguil in good years. This figure is used as reference for suitable land to produce switchgrass in the current situation. Years with drought and climate limitations have shown annual yields of 3.9–5.2 tdm/ha [55]. A yield of 5 tdm/ha/year is used as reference for mS land for the current situation (see Fig. 8). Future yields are based on the data used in the assessment of the biomass for energy potential. The scenarios suggest a 32–67% yield increase to 2030 compared to the current situation.

4.2.3. Transport, processing facilities and energy supply in and around the selected region

National highways are available throughout the country and in La Pampa province. Railways run from Santa Rosa, Telén and Arizona to Rosario or Bahía Blanca [47]. The western part of La Pampa province has no availability of railways. The majority of the train lines were privatized in 1992–1993, which means that the maintenance of the railway is largely the responsibility of private companies [56]. Although the train is more efficient for large-scale transport, most of the transport takes place via truck due to infrequency of train transport in the region [57].

There are several inland ship transport routes in the country such as Río de la Plata and its tributaries [15]. Ship transport is, however, not an option for La Pampa province. The province has limited superficial water sources: The Rio Colorado forms the southern border of the province and the second main river (Salado-Chadileuvú) goes from north to south in the western part of the province.

In Argentina, there are two main harbour areas for transport [58]. The first area are the harbour terminals from the Up River (terminals for oceanic transport centred in Rosario, San Lorenzo, Villa Constitución). This is a 90 km strip located south and north of Rosario, on the left side of the river Paraná. The second main area for oceanic transport is the harbour terminals south of Buenos Aires, centred in the custom harbours of Bahía Blanca (BB) and Necochea. The available capacity per transport is 66.000 t based on a Panamax ship. Ships leaving from harbour terminals further up the River Paraná leave with a cargo of around 48.000 t of grains based on a Panamax ship [58].

Rosario is the area with the largest concentration of oil crushing plants in the world. Its feedstock is almost exclusively soybean oil. The current oil milling capacity reaches 154×10^3 tons/day [27]. 85% of the installed milling capacity is divided among 6 major companies [27]. Biodiesel plants (in development) are located in Buenos Aires and Santa Fe [59]. Large pelletizing facilities are limited in Argentina. At this moment, only one pelletizer is working in Corrientes. There are five more projects in development, all with sawdust input and with a capacity ranging from 30×10^3 t/year to 100×10^3 t/year [60]. Electricity in La Pampa province is delivered by hydro plants and by natural gas fired power plants.

5. Defining the bioenergy chains

The bioenergy value chains for switchgrass and soybean production can be further specified based on the previous sections. Quantitative parameters shown in Table 6 (only shown for CUR and for the year 2030), relevant for calculating the economic performance of the bioenergy chains in each scenario, are added to the parameters presented in Table 1.

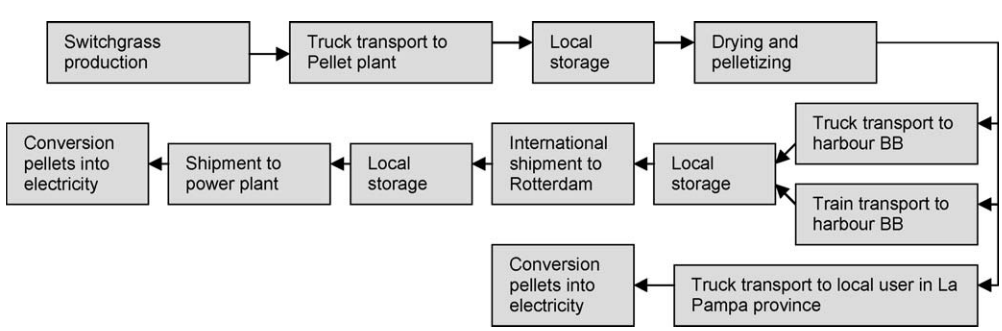

Fig. 9. Defined bioenergy production chain from switchgrass, produced in La Pampa province.

Table 6
Input parameters for economic performance bioenergy value chains from switchgrass and soybeans for current situation and for scenarios A, B and C for year 2030 for suitable (S) land and for marginally suitable (mS) land.

Parameter	CUR		Scenario A		Scenario B		Scenario C	
Available land for bioenergy soybeans in 1000 ha	S: 236	mS: 61	S: 125	mS: 61	S: 238	mS: 64	S: 122	mS: 45
Available land bioenergy from switchgrass in 1000 ha	S: 347	mS: 212	S: 161	mS: 212	S: 630	mS: 171	S: 756	mS: 214
Agricultural production system	Intermediate agricultural production system		Intermediate agricultural production system		Mixed agricultural production system.		High input agricultural production system	
Agricultural production system switchgrass	No irrigation Lifetime plantation: 15 years Seeding: 3 kg, seeds are imported Fertilizers: 50 kg N/year for S land, 14 applications. Herbicides: in 1st and 2nd year of establishment with common herbicides Harvesting: once per year No-tillage system mS land requires lower inputs fertilizer and agrochemicals		No irrigation Lifetime plantation: 15 years Seeding: 3 kg, seeds are imported Fertilizers: 50 kg N/year for S land, 14 applications. Herbicides: in 1st and 2nd year of establishment with common herbicides Harvesting: once per year No-tillage system mS land requires lower inputs fertilizer and agrochemicals		No irrigation Lifetime plantation: 20 years Seeding: 3 kg needed, available in country Fertilizers: 50 kg N/year and 25 kg P/year for S land, 28 applications. Herbicides: in 1st year of establishment, herbicides specified for switchgrass Harvesting: once per year No-tillage system mS land requires lower inputs fertilizer and agrochemicals		No irrigation Advanced developments in seed technology to improve yields and weather resistance. Lifetime plantation: 17.5 years Seeding: 3 kg needed, available in country Fertilizers: 50 kg N/year and 25 kg P/year, in total 28 Herbicides: in 1st and 2nd year of establishment, herbicides specified for switchgrass. Harvesting: twice a year No-tillage mS land requires lower inputs fertilizer and agrochemicals	
Agricultural production system soybean	Direct seeding in combination with rotation of crops. Transgenic seeds are used. Use of fertilizers and herbicides Reduced tillage mS land requires lower inputs fertilizer and agrochemicals		Conventional cropping system (no direct seeding) Reduced tillage mS land requires lower inputs fertilizer and agrochemicals		Use of fertilizers and herbicides (organic if available). GM seeds for soybean production are used, further development is not promoted. Direct Seeding in combination with other conservation measures to improve sustainability No tillage mS land requires lower inputs fertilizer and agrochemicals		Advanced developments in seed technology to improve yields and weather resistance. Use of fertilizers and herbicides. Direct Seeding Reduced tillage mS land requires lower inputs fertilizer and agrochemicals	
Soybean yield in tdm/ha	S: 2.8	mS: 1.7	S: 3.1	mS: 1.9	S: 3.2	mS: 1.0	S: 3.5	mS: 2.3
Switchgrass yield in tdm/ha	S: 10.0	mS: 5.0	S: 13.2	mS: 6.6	S: 14.6	mS: 7.3	S: 16.7	mS: 8.3
Reference land use	S: crop production (C) mS: degraded grassland (D)		S: crop production (C) mS: degraded grassland (D)		S: non-degraded grassland (G) mS: degraded grassland (D)		S: crop production (C) mS: degraded grassland (D)	
Environmental and economic priorities	Average environmental awareness.		Average environmental awareness due to economic constraints. Protection of the internal market is considered a priority.		High environmental awareness. Diversification of landscape and renewable energy sources is promoted.		Low to average environmental awareness. Economic growth and competition on the internal market is considered a priority.	
Economic trends and costs	Current situation		Continuation of current trend economy. Energy and fuel prices remain subsidized to keep prices low. Renewable energy sources do not have a key priority. Biodiesel remains an export product. Labour costs increase slowly		Rise in economy Focus on main agricultural products High environmental awareness leads to promotion of renewable energy sources, both for export and local use, and to an increase in the fuel price Increase in labour costs		Strong rise in economy Focus on high value end-products Increase in energy and fuel prices according to international market. Biodiesel is strongly promoted Strong increase in labour costs	
Technology level applied	Current situation		Processing plants (e.g. pellet plants) are used on a small scale.		Making use of larger processing plants available in the Latin American region.		Up-scaling of processing plants (state of the art technology in the world)	

5.1. Defining the bioenergy chain for switchgrass production

The bioenergy production chain for switchgrass is shown in Fig. 9. After the harvest, the product is transported to the closest pellet plant. The pellets are exported to Rotterdam to be converted into electricity in a power plant in the Netherlands or used in the local market. Information from Smeets et al. [61] about the management of switchgrass for one production cycle forms the basis for specifying the applications of the switchgrass plantation in this case study. The information is further specified to the Argentinean situation by using information from a 13 year old test of using switchgrass for bioenergy production from INTA based in Anguil in La Pampa province [55]. Input parameters are diversified for the different scenarios (see also Table 6). In this study, we assume a lifetime of the switchgrass plantation from 15 to 20 years depending on the scenario, based on [13,52,61].

Based on experiences from Petruzzi [55], October and November are considered optimal seeding months as the risk for frost is limited. Results show however, that lack of rainfall and the occurrence of severe drought in the first months after seeding can have a great influence in the survival of the attained plants. Economically viable crop yields require fertilization rates between 50–100 kg/ha/year. The effect of N fertilizer, however, can be site specific. On more fertile sites, effects have typically been negative or neutral [62]. N fertilizer can increase yields if there is sufficient rainfall in that year [45]. Test results show that the use of

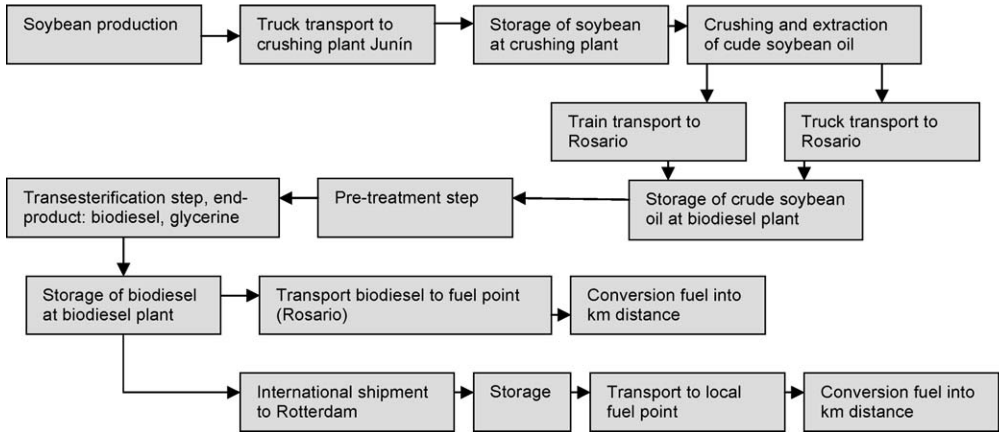

Fig. 10. Defined bioenergy production chain from soybeans, produced in La Pampa province.

P-fertilizer and calcium is not needed in INTA Anguil but P-deficiencies are recorded in some other regions in La Pampa province [45]. Weeds can be an obstacle for switchgrass establishment. In the first year after seeding, herbicides may be needed to control weeds [13]. This is confirmed by Petruzzi [45], recommending the use of herbicides in the 1st and/or 2nd cycle of the crop. Once a good stand is established, the use of herbicides is no longer needed.

Stands are typically not harvested during the first growing season. There after, the highest yield per hectare can be obtained when switchgrass is harvested once or twice per year [62]. Data from [55] show that differences in total yield are small for one or two harvests per year when no fertilizer is applied. The appropriate harvesting date in La Pampa province is still being examined, but is expected to be around April-July [52]. In this study it is assumed that the grass is harvested and turned into bales. A mounted big baler machine, conform the study from Smeets et al. [61], is used for harvesting. The moisture content from Switchgrass after harvest is 15% [63]. The bales are directly transported to the nearby pellet plant for storage. The removal of the plantation includes two times of rotary cultivating and one time of spraying [61].

5.2. Defining the bioenergy chain for soybean production

The bioenergy production chain for soybean is shown in Fig. 10. After harvesting, the product is transported to Junín for oil extraction. This is the closest processing unit for soybean production in the region [57]. In Argentina, only larger agricultural companies will directly export the soybean to the oil extraction companies. The smaller to medium sized producers sell their soybean in practice via cooperatives or stocking companies spread in the country, who take care of the merchandise and send it to industry or to the harbour, where it is commercialized via the stock market [64]. After oil extraction, the crude soybean oil is transported to Rosario to be converted to biodiesel. This end-product is exported to Rotterdam or used in the local market.

Almost all soybean production in Argentina is seeded with GM seeds. The so-called "Roundup Ready" (RR) soybean is resistant against the herbicide glyphosate: the soybean is not affected when surrounding weeds are eradicated. Around 80% of the Argentinean farmers combine the use of RR-seeds with the practice of 'direct seeding' [11]. According to [20,65,66], direct seeding in combination with a rotation system is the dominating agricultural system for soybean production in La Pampa province. The cultivation of transgenic soybeans is profitable for Argentinean farmers due to higher yields and reduction of costs. There is only a small surcharge for the use of transgenic soybean seeds [18]. In the scenarios, green manure seeds (only for scenario B) and RR-seeds are used as inputs with a rate of 80 kg/ha, differentiated to the various production systems [67]. Data about required agrochemicals input per scenario are based on [67,68].

Often, soybean is grown in crop rotation patterns. In case of double cropping (in rotation with wheat), seeding takes place in the months October ('Soja Primera') or January ('Soja Segunda') and harvesting in the months March to June [18]. In La Pampa province, most of the soybean comes from so-called 'Soja Primera'. As water is a limiting factor, the second cultivation only takes place if there is enough water available [69].

P and N input for soybean production are not needed for the current situation in La Pampa province according to Negri [70]. However, data from AACREA [67] give an input of 80 kg/ha monoamonico phosphate for the conventional and direct seeding (with fertilization) system and data from Panichelli [71] give a fertilizer input of 7.5 kg/ha triple superphosphate and 18 kg/ha monoamonico superphosphate for the direct seeding system during 1st cultivation. Due to the current imbalance of nutrients in crop cultivation in Argentina [72] and expected intensification of agriculture, an increase of fertilizer is assumed for the future scenarios. Less fertilizer input is assumed for scenario B due to an increased use of environmental friendly methods.

At the start of the crushing process, the soybean has a moisture content of 10–10.5%. After the crushing process, 17% of the final output is oil, 80% sub-products (soybean pellets) and 3% waste [73]. The current oil milling capacity reaches 154×10^3 tons/day [27]. Soybean and sunflower absorb 99% of the available crushing capacity [74]. The technology applied for the production of oil from soybean on large-scale is solvent extraction [74].

The production process of biodiesel is relatively simple. After extraction, the oil is usually filtered in a pre-treatment step to remove water and other contaminants. In the actual biodiesel production step, the transesterification step, the oils are blended with an alcohol (usually methanol) and a catalyst. This leads to the breaking of oil molecules, which reforms into esters (biodiesel) and glycerine [27].

6. Economic feasibility of selected bioenergy chains in La Pampa province

6.1. Methodology

The costs for bioenergy production for the two defined chains are calculated for the scenarios. Cost data collected from 2007 to

Table 7
General cost and price items for the soybean and switchgrass bioenergy chain for current situation and for the defined scenarios A, B, and C in 2030.

General Cost and price items	Unit	Scenarios				Refs.
		CUR	A2030	B2030	C2030	
Interest rate (IR)	In %	8% (ARG), 6% (NL)	12%	2%	4%	[89,90,96]
Soybean oil R'dam (FOB)	US$/t	1511	1587	1587	1587	[97]
Soybean pellets R'dam (FOB)	US$/t	455	455	466	479	[97]
Soybeans BA (FOB)	US$/t	540	567	540	554	[97]
Soybean pellets BA (FOB)	US$/t	385	385	431	404	[97]
Soybean oil BA (FOB)	US$/t	1390	1460	1523	1587	[97]
Glycerine price	US$/t	50	5	20	10	[27,79,80]
Price free fatty acids	US$/l	0.05	0	0.05	0.1	[27,65,74,76]
Pellet price	US$/t	183	229	275	238	[82,84,91]
Diesel price ARG	US$/l	0.5	0.7	1.1	0.9	[83]
Diesel price NL	US$/l	1.3	1.3	1.3	1.1	[83]
Labour cost manufacturing ARG	US$/h	2.2	4.0	8.7	13.4	[92]
Labour cost manufacturing NL	US$/h	33.3	33.3	33.3	36.1	[61,81]
Labour cost agriculture ARG	US$/h	3.2	5.9	8.7	13.4	[85,92]
Natural gas price	US$/m^3	0.1	0.2	0.4	0.2	[65,78]
Electricity price ARG (La Pampa)	US$/kWh	0.02	0.05	0.08	0.05	[75,88]
Electricity price NL	US$/kWh	0.15	0.15	0.15	0.13	[81,87]
Land rent Switchgrass S land	US$/ha/year	130	195	124	111	[55,69]
Land rent Switchgrass mS land	US$/ha/year	110	110	121	110	[55,69]
Land rent Soybean S land	US$/ha/year	150	225	150	225	[55,69]
Land rent Soybean mS land	US$/ha/year	130	130	130	195	[55,69]
(Cooling) water industry ARG	US$/t	0.09	0.1	0.15	0.13	[22,94,95]
(Cooling) water industry NL	US$/t	0.17	0.17	0.2	0.19	[86,93]
Price for heat/steam ARG	US$/kWh	0.006	0.01	0.014	0.02	[65,77]
Price for heat/steam NL	US$/kWh	0.009	0.01	0.02	0.02	[77]
Export tariff biodiesel	In %	17.5	20	10	15	[55]
Export tariff vegetable oil	In %	41	40	30	15	[55]
Export tariff pellets	In %	10	15	5	15	[55]

the beginning of 2008 are used as a basis for the current situation. The conversion of cost data from € to US$ (or vice versa) is based on February 2008[1]. Future costs and market prices are based on the main characteristics of the different scenarios to 2030 (see Tables 1 and 6). Unless indicated else, the prices for 2015 are the average between the price or cost for 2030 and the current situation. General cost and price items used in the calculations for the soybean and switchgrass bioenergy chain are shown in Table 7 [22,27,55,61,65,69,74–97].

6.1.1. Cultivation on the land for biomass production

The cultivation costs are the sum of the cost for land rent, fertilizer, agrochemicals, seeds, labour and machinery, harvesting costs and operation and maintenance (O&M) and depend on the required inputs (as explained in 4.1 and 4.2) and the assumed price level per input required. Table 8 shows the main cost and price items for biomass cultivation [54,67,98–106].

Input data for the current scenario of soybean cultivation are based on a cost analysis from Negri [65] for a 'direct seeding' production system for the 1st cultivation situated west of Buenos Aires province. To differentiate these data to the production systems assumed for the scenarios (see Table 6), economic analyses from AACREA [67] for a conventional and a direct seeding (with and without fertilization) soybean production system are used. The required fuel and labour input for harvesting is based on data from Donato [73]. The economic analysis for soybeans [67] includes an assessment of the harvesting and marketing costs. Marketing costs are the costs related to local storage, sealing, drying (3% moisture decrease), local taxes, collecting and local transport [67]. In our study, local transport costs are not included in the marketing costs as they are calculated as a separate cost unit (see also Section 6.1.2). The calculation of the harvesting and marketing costs for soybeans is based on price and yield levels presented in [65,67]:

$$\text{Marketing costs} = 6\% \times (\text{soybean price in US\$/ha}) \times (\text{yield in t/ha}) \quad (1)$$

$$\text{Harvesting costs} = 8\% \times (\text{soybean price in US\$/ha}) \times (\text{yield in t/ha}) \quad (2)$$

In Argentina, labour and machinery costs are expressed in a unity called 'Unidad Técnica Arada' (UTA). This unity includes fuel use, maintenance and reparation of machinery, depreciation and interest, personal or manual labour and administration costs [73]. The total 'UTA' costs for soybean production from [65,67] are differentiated to the individual agricultural activities with data from [101]. Ultimately, the machinery and labour costs for soybean production (excl. harvesting) per agricultural activity are calculated with data from [73] about the required labour and fuel input per agricultural activity for a defined soybean production system.

UTA costs are also provided for the implantation of pasture, which can potentially be a reference for switchgrass production. However, available data show a large variety in implantation costs according to the type of pasture planted, selected region and year [107,108]. Due to this large data variety and the lack of required input data for various management systems, it is decided to use the input and cost data on switchgrass cultivation in Europe from Smeets et al. [61] as a basis to calculate labour and machinery costs. Labour and fuel costs are an outcome of the required input per agricultural activity (including harvesting) multiplied by the cost per input. The cost of machinery is divided into capital, operation and maintenance, fuel, labour, storage, insurance and others. The Argentinean purchase price [109] is used for tractors, loaders and trailers. For the other agricultural machines, Argentinean purchase prices were not available or not specified enough. In this case, the purchase price is based on Smeets et al. [61].

Switchgrass seeds (see Table 8) currently need to be imported from Texas at a cost price of 20 US$/kg. In case seeds would be

[1] 19 February 2008: 1€ = 1.47 US$.

Table 8
Cost data for biomass for energy cultivation in La Pampa province in Argentina for the current situation and for the scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				Refs.
		CUR	A2030	B2030	C2030	
N fertilizer Urea	US$/kg	0.5	2.0	1.7	1.4	[67,100–102,104]
P fertilizer (Superphosphate)	US$/kg	0.5	1.9	1.6	1.3	[67,100–102,104]
P fertilizer (monoamonico)	US$/kg	0.6	2.4	2.0	1.6	[67,100–102,104]
Agrochemical Atrazina[a]	US$/unit	2.9	6.4	4.6	3.6	[67,98,103,105,106]
Agrochemical Roundup Max	US$/unit	17.8	40.1	29	22.3	[67,103,105,106]
Agrochemical Cipermetrina	US$/unit	5.6	12.6	9.1	7.0	[67,103,105,106]
Agrochemical Inoculante	US$/unit	3.7	8.3	6.0	4.6	[67,103,105,106]
Soybean seed RR	US$/kg	0.2	0.2	0.2	0.1	[67,99]
Green manure seed soybean	US$/kg	0.5	0.5	0.5	0.4	[67]
Switchgrass seed	US$/kg	15	15	10	12.5	[54]

[a] Not all agrochemicals used for soybean cultivation are indicated in this table.

produced in the country, the cost would probably be around 10 US$/kg, as seeds from similar species (Kleingrass or Digitaria) that are produced on the local market are about half the price [110]. Seeds can be easily produced by seed harvesting on the switchgrass plantation which generates seeds for future cultivations [52].

One of the relevant costs for biomass cultivation is land rent. Current land rental prices in Argentina are high, also compared to other countries [111], and both land rent as the value of land fluctuate strongly between land use types, [85] and expected crop prices[2] [112]. The indication of land prices for S and mS land for 2007 in the selected region by various authors [45,69,96,113,114] ranges from 100 to 450 US$/ha $\times$ year depending on land suitability type, location and crop type.

6.1.2. Transport and storage of biomass products

The cost for transport is shown in Table 9 in US$/tkm [56,58,61,115–117]. Calculating the transport distance from the roadside of the field to the first processing unit is based on the approach taken by [15,42]. The delivery area for a processing unit is the area of land needed for meeting the energy crop demand of the processing unit. Portraying this delivery area as a circle, with the processing unit in the centre of it, and various production fields located inside, allows the calculation of the average transport distance from the roadside of an energy crop field to the processing unit as the radius of this circle. The size of the delivery area depends on the energy crop yield and the coverage of the crops (as % of the total land). Multiplying these two parameters gives the distribution density of the energy crop. It is assumed that there is a uniform distribution density within the delivery area, so that the average transportation distance from the roadside to the first processing unit is calculated using Formula (3):

$$R = \sqrt{\frac{P}{(2 \times \Pi \times Y \times C)}} \tag{3}$$

Where: R = average transport distance from roadside field to processing unit in km^2; P = Capacity processing unit in tons/year; Y = Energy crop yield (in tons/km^2/year); C = coverage of energy crop (as percentage of total land area).

Distances from the 1st processing unit onwards to the next facilities are shown in Table 10 [57,91,118–120]. Truck transport from the farm to the first processing unit is ‘dedicated’, meaning that the truck has no load on its return. Transport from the first

Table 9
Transportation costs for various transport modes used in the switchgrass and soybean bioenergy chains for the current situation and for the scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				Refs.
		CUR	A2030	B2030	C2030	
Truck transport	US$/tkm	0.06	0.12	0.18	0.19	[58,61,115]
Train transport	US$/tkm	0.03	0.03	0.05	0.07	[58,61,115]
Sea ship transport	US$/tkm	0.007	0.007	0.008	0.009	[56,58,115,117]
Inland ship transport	US$/tkm	0.14	0.14	0.09	0.03	[61]
(Un)-loading ARG	US$/tdm	3.0	3.3	3.8	4.0	[61,116]

Table 10
Transport distances (in km) for soybean and switchgrass bioenergy chains.

	Distance in km.	Refs.
Pellet Plant to Bahía Blanca harbour area	327	[120]
Pellet plant to local user La Pampa province	50	Own estimation
Bahía Blanca to harbour Rotterdam	12024	[119]
Harbour Rotterdam to power plant	50	[91]
Crushing plant Junín to Rosario by truck	208	[118]
Crushing plant Junín to Rosario by train	200	[57]
Rosario to harbour Rotterdam	12303	[119]
Harbour Rotterdam to fuel point	0	Biodiesel is used in Rotterdam harbour
Biodiesel plant Rosario to local fuel plant	10	Biodiesel is used in industrial area Rosario

processing unit to the next stop onwards is ‘non-dedicated’, meaning that there is new cargo for the return trip and therefore costs are calculated for a one-way trip only.

Local storage costs for soybeans are included in the marketing costs (see Formula (1)). Storage for switchgrass bales is located at the pellet plant, stored outside the pellet plant under a plastic roof. The costs involved are based on data from [61,68,121]. Storage costs of the pellets are included in the costs for pellet production. A dry matter loss of 2.5% is assumed for all scenarios, based on data from Hamelinck et al. [122]. As pellets are stored at the pellet plant, it is assumed that storage at the harbour is only needed for limited time.

In the current situation, the plants in Rosario load the biodiesel produced directly in the ships due to lack of storage capacity. The crude soybean oil is stored at the crushing plant in Rosario and thus closely located at the harbour. Due to large fluctuations in storage costs at the harbour areas in Argentina [95,123] and the expected limited storage time at the harbour for all products defined, the storage costs at the harbour in Argentina is assumed to be zero. Once the products arrive in the Netherlands, there are no storage

[2] End of 2008, soybean prices dropped substantially from 600 to 300 US$/ton. This resulted in a similar decrease in land rents for this period, showing the sensitivity of land rents to (international) crop prices.

Table 11
Cost data for processing facilities included in switchgrass bioenergy chain for current situation and for the scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				Refs.
		CUR	A2030	B2030	C2030	
Annual capacity pellet plant	In 10^{+3} tdm	35	45	73	100	[77,84]
Load pellet plant	H/year	7884	7884	7972	8000	[60,77]
Drying machine used	Unit	Tube bundle dryer	Tube bundle dryer	Drum dryer	Superheated steam dryer	[77,124]
Storage type pellet plant	Unit	Silo	Silo	Warehouse	Warehouse	[77]
Capacity power plant[a]	MW (el)	10	40	40	40	[125]
Investment power plant[b]	€/kW (el)	250	250	230	230	[125]
O&M costs power plant	% inv.	38%	38%	38%	38%	[125]
Net electric ή	Mje/MJlhv	37%	44%	44%	44%	[125]
Capacity boiler	MW (th)	2	2	2	2	[125]
Investment costs boiler	€/kW th	450	450	420	400	[125]
O&M costs boiler	% inv.	4%	4%	4%	4%	[125]
Net heat ή	MJth/MJlhv0	0.87	0.9	0.9	0.9	[125]

[a] Only capacity of electricity produced from biomass is given.
[b] Investment costs for co-firing, and costs are additional costs of biomass co-firing while the basic investments for the fossil fuel power plant are not taken into account.

costs as the products are directly transported to the power plant or biodiesel plant.

6.1.3. *Processing and conversion facilities*

Cost estimations for processing and conversion facilities are based on the required inputs and the price per input, see Tables 7 and 11, [60,77,84,124,125] and Table 12 [22,27,64,65,69,74,126–132]. Economies of scale, included in the cost calculations, play a role in the investment costs when the scenarios assume a larger plant scale or when it is assumed that more plants need to be installed to fulfil demand. The Producer Price Index (PPI) from [133] is used as a reference to differentiate investment costs of machinery between the Netherlands and Argentina and between scenarios, each characterised by its level of economic growth. PPI measures the average change in selling prices, received by domestic producers of goods and services over time and is used as a basis to estimate investment costs for the biodiesel and pellet plant.

Pelleting costs include fixed and operating costs. Pelleting costs for Argentina are based on [77,134] where Thek [135] provides a basic structure to analyze costs for pellet production based on wood for the Austrian and Swedish situation. Input data such as fuel, electricity and labour costs are specified for Argentina. Cost data about machinery for pellet plants in Argentina are limited although some information is provided by [57,136].

It is assumed that pellets in the Netherlands are used to generate electricity in coal-fired plants. During co-firing, the biomass is mixed with coal. Typical co-firing ratios are up to 10% while in newer multi-fuel power plants higher shares of about 40% are possible. The lifetime of the plant is 20 years with a load factor of 6500 h/year for all scenarios. It is assumed that pellets in Argentina will be used for district heating and for heating of larger buildings or process heat in small enterprises. Conversion takes place in an industrial, medium scale boiler with a lifetime of 20 years and a load factor of 4000 h/year for all scenarios.

The cost to convert pellets into electricity or heat is calculated from the yearly capital and operational costs of the installation, the yearly fuel costs, the efficiency of conversion, the operation hours in a year and possible revenues from by-products using formula 4 [125]:

$$C_e = \frac{\mathrm{INV} \times (af + \mathrm{OM})}{lf \times 3600} + \mathrm{M_{by\text{-}p}} \times \mathrm{P_{by\text{-}p}} \tag{4}$$

Where: C_e = Cost of energy production (electricity, heat) in US$/MJ; INV = Specific investment costs per output capacity (electricity, heat) in US$/MW; *af* = Annuity factor; OM = Yearly operation and maintenance costs as ratio of total investment in 1/year; *lf* = Load factor of conversion installation in hours/year; $M_{by\text{-}p}$ = Amount of by-product in MJ_{th} or MJ_{el} per MJ_{energy}; $P_{by\text{-}p}$ = Price of by-product in US$/$MJ_{th}$ or in US$/$MJ_{el}$.

The crushing facilities in Argentina are privately owned. It is therefore difficult to obtain cost data for this part of the biodiesel value chain. Indicated cost levels range from 5 to 12 US$ per ton grain [64,65,137]. For the current situation, we assume a cost of 8 US$ per ton grain for the crushing process. A cost breakdown of the crushing process from Larizzate [123], excluding input costs from

Table 12
Data for processing facilities in soybean bioenergy chain for current situation and for scenarios A, B and C in 2030.

Cost items	Unit	Scenarios				Refs.
		CUR	A2030	B2030	C2030	
Capacity crushing plant [a]	Ton oil/day	2000	4000	6000	8000	[64,69]
Capacity biodiesel plant	Liter/day	46000	40.000	100.000	200.000	[65]
Load	Days/year	359	359	359	359	[65]
Methanol price ARG	US$/kg	0.7	1.5	2.0	1.1	[27,126,127]
Methanol price NL	US$/kg	0.8	1.7	2.0	1.1	[27,126,127]
Hexane price	US$/t	1000	2875	2250	1625	[130,132]
Sodium hydroxide ARG	US$/t liq.	540	878	1148	1148	[22,129,130]
Sodium hydroxide NL	US$/t liq.	480	780	1148	1148	[22,129,130]
Sulphuric acid price	US$/kg	1.6	4.6	3.6	2.6	[22,131,132]
Phosphoric acid price	US$/kg	0.1	0.4	0.2	0.2	[22,131,132]
Water treatment cost ARG	US$/l biod.	0.24	0.48	0.48	0.47	[74,128]
Water treatment cost NL	US$/l biod.	0.48	0.48	0.48	0.47	[74,128]

[a] Larger crushing plants are available in Argentina in the current situation. However, due to the (for some scenarios) limited availability of soybean for bioenergy production, a smaller size is selected to limit the transportation distance for delivery of the input product.

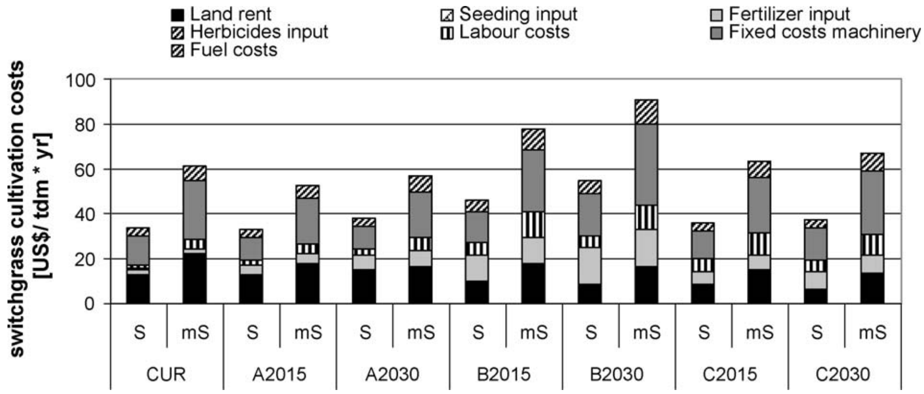

Fig. 11. Switchgrass cultivation costs in US$/tdm for defined land suitability types (mS and S land) for the current situation and for scenarios A, B and C in 2030.

the grains is used in this study: 40% variable costs, 30% fixed costs including employment and 30% amortization costs. The required amount of inputs (electricity, natural gas, water, chemical inputs) for the oil extraction process is taken from [74]. The required labour input is estimated with information from [74,123,138]. The calculated total crushing costs are allocated over the pellets and crude soybean oil, based on the mass balance (97×10^3 tons of crude soybean oil, 457×10^3 tons of pellets for an input of 572×10^3 tons of grains) of the output products.

In this study, the transesterification process takes place in Rosario or, alternatively, in Rotterdam. It is assumed that on each location the same plant capacity is used. The input-output balance for the biodiesel production process is based on information on the mass balance for the transesterification process from [22,27,73,74]. Input data for electricity and heat for the transesterification process are from [74]. The required amount of labour input and data on investment costs for biodiesel plants are taken from [70]. The availability of free fatty acids is estimated as 12.6% of the generated glycerine production [70]. Extra revenues from free fatty acids depend on price and demand. A price of 0.20 US$/l is given by [70]. Several studies [27,74,76] do, however, not consider free fatty acids as a by-product but as a waste with no value.

Biodiesel cost estimations from Argentina do not mention an extra cost for waste water treatment, although the item is indicated by [74] for the extraction and transesterification process. Waste water treatment costs vary per location due to different environmental regulations [128]. In the study from [128], a cost for waste water treatment of US$ 50.000/year for a biodiesel plant of 105.000 l biodiesel/day is used (0.48 US$/l biodiesel/day). Water treatment costs are included for all scenarios (see Table 6). New technologies reduce the amount of waste water in the system [20], which is considered for scenario B and C.

6.2. Economic analysis switchgrass bioenergy chain

Switchgrass cultivation costs (Fig. 11) range from 33 (A2015-S) to 91 US$/tdm (B2030-mS). For comparison, calculated switchgrass production costs in various countries in Europe range from 46 to 119 US$/tdm or 31 to 81 €/tdm [61]. We can assume that switchgrass cultivation (with a cost range of 339 to 306 US$/ha/year for CUR on S and mS land respectively) is competitive with alfalfa production in the current situation as alfalfa production costs for bales in the same region (land suitability type undefined) are estimated in 2008 at 320 US$/ha/year with a margin of 176 US$/ha year [69]. This study has calculated purely the costs for switchgrass cultivation and profits are excluded in the analysis. Although the margin for switchgrass cultivation is not defined, depending largely on the demand of the product, a similar margin as for alfalfa production is realistic though.

For comparison, current livestock production costs in La Pampa province are estimated at 36 US$/ha with a net margin of 17 US$/ha [139], based on a price of 1300 US$/cow [140]. As the margins for livestock production are considerably lower than for alfalfa production, switchgrass production is expected to be competitive with livestock production and other, similar land uses in the region.

In all scenarios, costs for switchgrass cultivation on mS land is higher than on S land due to lower yields and relatively higher fixed costs (e.g. land rental). The contribution to total cultivation costs is, depending on the scenario, 15–39% for land use, 36–54% for machinery and fuel costs and 3–30% for fertilizer costs. The variation of the latter is due to assumptions about fertilizer input (see Section 4) and the price per unit of fertilizer in each scenario.

Table 13 presents the calculated pellet production costs for the current situation and for the scenarios to 2030 compared to a range

Table 13
Pellet production costs in US$/tdm delivered at harbour Rotterdam (for export chain) or at end-user in Argentina (for local use) for current situation and for scenarios A, B and C to 2030. Cost margins (assumed pellet production costs in Europe minus calculated costs) are indicated for the export chains.

Scenario	CUR		A2030		B2030		C2030	
	Land suitability type							
	S	mS	S	mS	S	mS	S	mS
Pellet production costs Europe (low)	110	110	110	110	110	110	110	110
Pellet production costs Europe (high)	205	205	205	205	205	205	205	205
Cost pellet at harbour ROT (truck)	163	196	218	240	252	297	253	296
Margin with European pellet costs (low)	−53	−86	−108	−130	−142	−188	−143	−186
Margin with European pellet costs (high)	42	9	−13	−35	−46	−92	−48	−91
Cost pellet at harbour ROT (train)	150	184	183	214	211	282	214	270
Margin with European pellet costs (low)	−40	−74	−73	−95	−95	−141	−101	−141
Margin with European pellet costs (high)	55	22	22	0	0	−46	−6	−49
Cost pellet at end-user (local use)	58	88	80	89	100	143	80	117

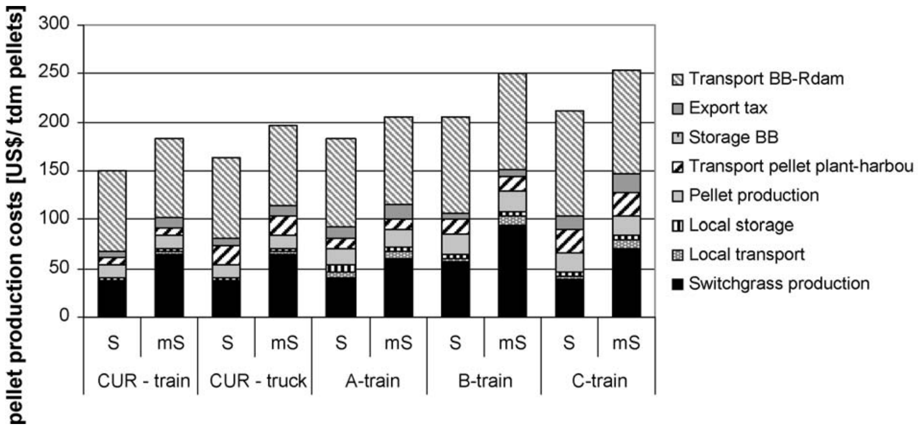

Fig. 12. Pellet production costs in US$/tdm. Pellets are produced in Argentina and delivered at harbour of Rotterdam, using truck or train for inland transport. Results are presented for defined land suitability types (mS and S land) for current situation and for scenarios A, B and C to 2030.

Table 14
Total conversion costs and margins for heating in Argentina (in US$/GJ) and electricity in the Netherlands (in US$/kWh) from switchgrass pellets for current situation and for scenarios A, B and C to 2030.

Scenario		CUR		A2030		B2030		C2030	
	Land suitability								
	Unit	S	mS	S	mS	S	mS	S	mS
Conversion costs	US$/GJ	16.7	18.5	19.7	20.9	20.4	22.8	20.2	22.5
Electricity (truck) NL	US$/kWh	0.06	0.07	0.07	0.08	0.07	0.08	0.07	0.08
Margin low[a]	US$/kWh	−0.01	−0.02	−0.02	−0.02	−0.02	−0.03	−0.02	−0.03
Margin high[b]	US$/kWh	0.03	0.02	0.01	0.01	0.01	0.0	0.01	0.0
Conversion costs	US$/GJ	16.0	17.8	17.8	19.4	18.2	22.0	18.1	21.1
Electricity (train) NL	US$/kWh	0.06	0.06	0.06	0.07	0.07	0.08	0.07	0.08
Margin low[a]	US$/kWh	−0.01	−0.01	−0.01	−0.02	−0.01	−0.02	−0.01	−0.02
Margin high[b]	US$/kWh	0.03	0.02	0.02	0.02	0.02	0.01	0.02	0.01
Conversion costs local	US$/GJ	9.6	11.3	8.9	9.9	7.9	10.2	7.0	9.0
Heating ARG	US$/kWh	0.03	0.04	0.03	0.04	0.03	0.04	0.03	0.03
Margin (in 1×10^{-2})	US$/kWh	−2.2	−2.8	−0.5	−0.9	1.1	0.3	2.3	−0.5

[a] Based on cost price electricity for coal of 0.05 US$/kWh.
[b] Based on cost price electricity for coal of 0.09 US$/kWh.

of estimated pellet production costs from 110–205 US$/tdm (75–140 €/tdm)) in Europe based on Thek et al. [77] and Peksa-Blanchard et al. [84]. Pellet production costs for local use, until delivery at the end user, range from 58 (CUR-S) to 143 US$/tdm (B2030-mS). Pellet production costs for the export chain, until delivery at the harbour in Rotterdam, range from 150 (CUR-S-train) to 297 US$/tdm (B2030-mS-truck). Most scenarios show a positive cost margin when a pellet production cost of 205 US$/tdm (140 €/tdm) is assumed. Scenario (C2030) is competitive when European pellet production costs are 253 US$/tdm (144 €/tdm). Pellet production from mS land shows in general higher costs than pellet production costs from S land (see Fig. 11). Transport of pellets from the pellet plant to the harbour by train instead by truck reduces costs for all scenarios.

Fig. 12 shows the contribution of the various cost items to total pellet production costs delivered at the harbour of Rotterdam for the selected scenarios. The contribution to total pellet production costs for the scenarios shown is 20% (C2030-S-train) to 44% (B2030-mS-train) for cultivation, 35% (B2030-mS-truck) to 55% (CUR-S-train) for oceanic ship transport, and 6% (CUR-mS-truck) to 10% (B2030-S-train) for the pelleting process. As shown in Plate 1, drying and pelletisation are the main cost items for pellet production.

Table 14 shows the total conversion costs in US$/GJ and US$/kWh for electricity in the Netherlands and for heating in Argentina generated from switchgrass pellets. Electricity costs for co-firing pellets in the Netherlands range from 0.06 to 0.08 US$/kWh. The chains producing switchgrass on S land with train as transport means have the best cost results. Current cost prices for electricity from coal in the Netherlands range from 0.05 to 0.09 US$/kWh, the latter including costs for carbon capture and storage [141]. The results in Table 14 show that the electricity costs for co-firing pellets in the current situation and in scenario (A2030) are close to the electricity costs from coal when costs for carbon capture and storage are excluded. All scenarios show a positive cost margin with the electricity costs from coal when costs for carbon capture and storage are included.

Heating costs in Argentina (local use) from pellets range from 0.02 to 0.04 US$/kWh. Differences between the various scenarios are limited. The current price[3] of natural gas for heating in Argentina is 0.12 US$/$m^3$ or 0.01 US$/kWh [65], including national taxes (≈10–20%) but excluding provincial or municipality taxes. The price of natural gas for future scenarios is based on defined fluctuations in the electricity price (see Table 7). Natural gas prices in Argentina are substantially lower than its surrounding countries (0.07, 1.47, 0.59 and 0.53 US$/$m^3{}_{2005}$ in Argentina, Brazil, Uruguay and Chile).

Heating costs in Argentina from switchgrass pellets, replacing natural gas, range from 0.02 (C2015-mS) to 0.04 US$/kWh (CUR2030-mS, A2030-mS and B2030-mS). The heating cost from switchgrass is competitive with the assumed heating price per

[3] Prices are used as cost estimates for heating from natural gas are not transparent in Argentina.

Table 15
Soybean biodiesel production costs and (in US$/l) for local use and for export for current situation and for scenarios A, B and C to year 2030, specified for defined land suitability types (S and mS land) and for the possibility of biodiesel conversion in Rotterdam (ROT) or in Rosario (ROS). Also indicated is the oil price (in US$/barrel) against which soybean biodiesel costs are competitive with fossil fuel costs.

Scenario	CUR		A2030		B2030		C2030	
	Land suitability type							
	S	mS	S	mS	S	mS	S	mS
Costs for export chains in US$/l								
Biodiesel processing in ROS-truck	0.5	0.6	0.9	1.1	0.8	1.2	0.8	0.9
Oil price (US$/barrel)	83	98	162	183	143	211	131	159
Biodiesel processing in ROS-train	0.5	0.5	0.9	1.0	0.8	1.2	0.7	1.0
Oil price (US$/barrel)	80	94	153	173	134	202	124	151
Biodiesel processing in ROT-truck	0.6	0.7	1.1	1.2	0.9	1.4	0.8	1.0
Oil price (US$/barrel)	101	118	183	207	157	238	132	160
Biodiesel processing in ROT-train	0.6	0.7	1.0	1.1	0.8	1.3	0.7	1.0
Oil price (US$/barrel)	96	113	175	199	149	229	126	153
Costs chain local use in US$/l								
Biodiesel processing in ROS-truck	0.3	0.4	0.7	0.8	0.7	1.0	0.6	0.7
Oil price (US$/barrel)	58	70	122	139	114	176	98	121
Biodiesel processing in ROS-train	0.3	0.4	0.7	0.8	0.6	1.0	0.5	0.7
Oil price (US$/barrel)	55	67	114	131	106	168	91	115

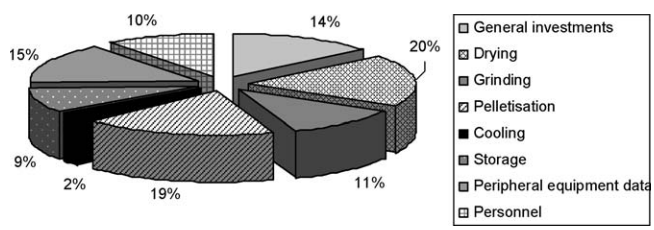

Plate 1. Relative contribution in % of various cost items to pellet production costs for scenario (CUR-S).

scenario (ranging from 0.012 to 0.027 US$/kWh for the various scenarios) in scenarios (B2030, C2030-mS) and close to competitive in scenario (A2030-S, C2030-mS). Based on the current low natural gas prices, switchgrass pellets for heating cannot compete with natural gas for heating in Argentina. Switchgrass pellets can, however, be used as alternative energy source for areas where natural gas is not available, see also Section 7.

6.3. Economic analysis soybean bioenergy chain

Cultivation costs (Fig. 13) range from 182 US$/tdm (CUR-S) to 501 US$/tdm (B2030-mS). In comparison, Berkum et al. [18] calculated a price of soybeans (CIF-Rotterdam) from Argentina and USA of respectively 225 US$/t and 299 US$/t including national transport to the harbour and an off-farm price of soybeans in Argentina of 145 US$/t. The difference between the calculated off-farm prices of soybeans between this study (CUR-S) and Berkum et al. [18] can be explained by differences in costs for herbicides and fertilizers: this is 59 US$/t in this study compared to 23 US$/t in [18]. The influence of input prices on cultivation costs is further discussed in Section 6.4.

Cultivation costs for alternative crops in or near the same region are around 427 US$/ha for wheat and around 183–218 US$/ha for sunflower (direct costs only) [69]. In general, sunflower cultivation costs are slightly lower than soybean production costs but differences in net margins (249 for sunflower and 248 US$/ha for soybeans in mid 2008) are negligible [140]. Soybean production for bioenergy purposes (348–440 US$/ha for CUR) is thus competitive with alternative, similar, land uses. Beside, soybeans can be sold to various markets (food, feed, fuel), which gives a farmer selling alternatives, in case of a decreasing demand in the biofuels market.

The contribution of cost items to total cultivation costs is, depending on the scenario, 23% (A2030-S) to 35% (CUR-S) for land rent, 20% (C2030-S) to 37% (A2030-mS) for agrochemicals and 0% (CUR) to 27% (B2030-mS) for fertilizers. The variation of the last two items can be explained by differences in costs per input (Table 7) and the assumptions behind the scenarios (Table 6).

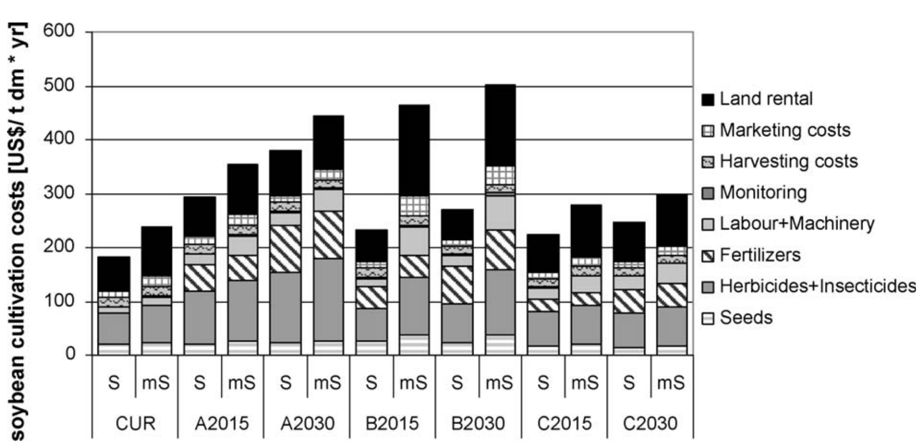

Fig. 13. Soybean cultivation costs in US$/tdm/year for defined land suitability types (S and mS land) for current situation and for various scenarios A, B and C in 2015 and in 2030.

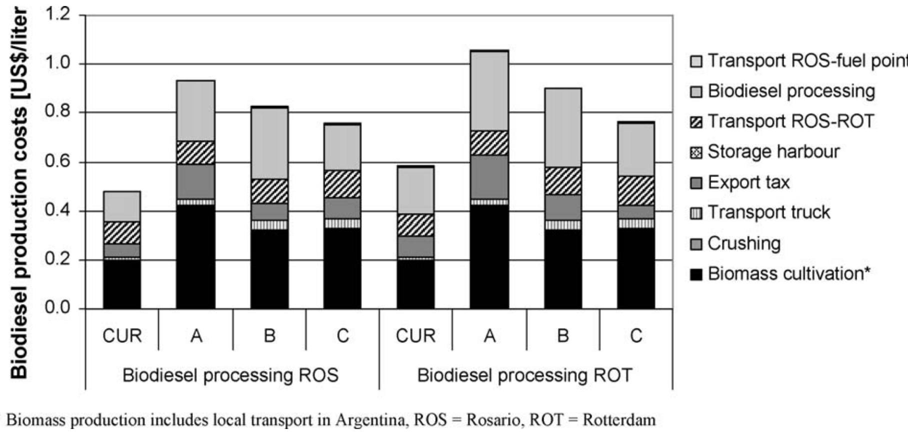

Fig. 14. Biodiesel production costs in US$/l, produced from soybeans in Argentina on S land. Results are shown for export chains using truck transport for current situation and for scenarios A, B and C in 2030. Biodiesel processing is located in Rosario or in Rotterdam.

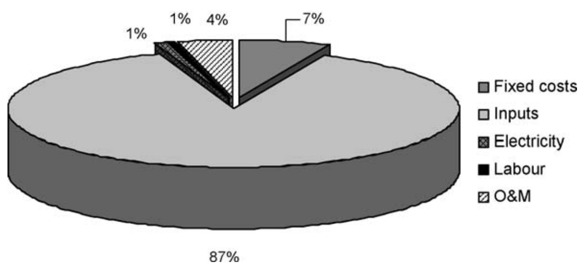

Plate 2. Relative cost distribution of transesterification process in biodiesel plant in Rosario for scenario (CUR-S-truck).

Table 15 shows the total biodiesel production costs for various scenarios. Biodiesel production costs for local use in Argentina range from 0.3 US$/l (CUR-S-train) to 1.0 US$/l (B2030-mS-truck), which is 10 to 34 US$/GJ respectively. Train transport from the crushing plant to the biodiesel plant instead of truck transport results in a decrease in final costs for all scenarios.

For comparison, Hoff [30] gives a biodiesel cost estimation of 0.5 US$/l. Net production costs for biodiesel calculated by Asal [22] and Lamers [27] are 0.4 US$/l without taxes (fuel transfer tax, diesel tax, taxes on profits for crude fuels) and 0.49 US$/l including local taxes for the year 2006. The difference in biodiesel production costs between this study and [22,27] can largely be explained by the assumption in costs for vegetable oil as input in the biodiesel production process as [22,27] use price data whereas this study uses cost data based on outcomes from previous steps in the bioenergy chain.

Biodiesel production costs for export to the Netherlands range from 0.5 US$/l (CUR-S-train-ROS) to 1.4 US$/l (B2030-mS-truck-ROT). This is 13.8 US$/GJ to 44.8 US$/GJ respectively. In comparison, current and future estimated production costs for biodiesel are 14.1 US$/$GJ_{2002}$ in the US (soybean, likely export price), 17.4 US$/$GJ_{2002}$ in EU15 (rapeseed), 13.9 US$/$GJ_{2020}$ in the USA, 17.2_{2020} US$/GJ in EU15 and 14.6 US$/GJ_{2020} in Eastern Europe [142].

The margins in Table 15 indicate the oil price[4] (in US$/barrel) that is needed to make the costs for soybean biodiesel competitive with the costs for fossil fuel. Current costs for soybean biodiesel, exported to the Netherlands, can be competitive with fossil fuel costs with an oil price of 80 US$/barrel, when produced on suitable land, and with an oil price of 94 US$/barrel when produced on marginal suitable land. Local soybean biodiesel production costs are competitive with fossil fuel costs with an oil price of 55 US$/barrel, when produced on suitable land, and with an oil price of 67 US$/barrel when produced on marginal suitable land.

The contribution to total biodiesel production costs (see Fig. 14) for the selected scenarios is 9% (A2030-ROT) to 18% (CUR-ROS) for oceanic ship transport, 33% (CUR-ROT) to 44% (A2030-ROS) for cultivation including local transport costs and 7% (C2030-ROT) to 17% (A2030-ROT) for taxes. Cultivation and transportation costs contribute together 61% to the total costs (in CUR-ROS) compared to 27% for the crushing and transesterification process in the same scenario.

It is cheaper to locate the biodiesel processing facilities in Rosario than in Rotterdam (see Fig. 14, Table 15). Plate 2 shows the relative cost distribution of the transesterification process for a biodiesel plant in Rosario for (CUR-S) excluding the income provided by the selling of by-products. By-products in the transesterification process are glycerine and free fatty acids. The selling of these by-products reduces the biodiesel processing costs from 379 to 373 US$/t biodiesel for (CUR-S-truck) which is around 1%. The relative cost distribution of the transesterification process for a biodiesel plant in Rotterdam shows a slightly different picture than the cost distribution shown in Plate 2 for a biodiesel plant in Rosario: 83% inputs (including oil and other chemicals), 1% electricity, 10% labour, 1% operation and maintenance (O&M) and 4% fixed costs. The differences in relative cost distribution between biodiesel processing in Rotterdam and Rosario is explained by higher costs for oil input in Rotterdam (as ship transport and taxes are already included) and variations in price assumptions (Table 7).

6.4. Sensitivity analysis economic results bioenergy chains

The economic analysis is based on cost data for the current situation, collected from September 2006 to August 2008. Prices in Argentina fluctuate strongly over time. For example, the price for Urea fertilizer increased from 0.5 US$/kg in august 2007 [68] to 0.73 US$/kg in august 2008 [140] and soybean prices dropped from 600 to 300 US$/t in one month in the 3rd quarter of 2008 [112]. The cost data for (CUR) reflect therefore a snapshot of the current situation. This also explains some of the differences in cost results between various studies of soybean and biodiesel production available in Argentina. In addition, required inputs for soybean production vary strongly per region and production system, which is not specified by Berkum et al. [18]. Total direct costs for the first

[4] Fossil fuel costs: based on oil barrel price in US$/barrel (6.38 GJ/barrel) plus 10% extra costs for refinement and transport.

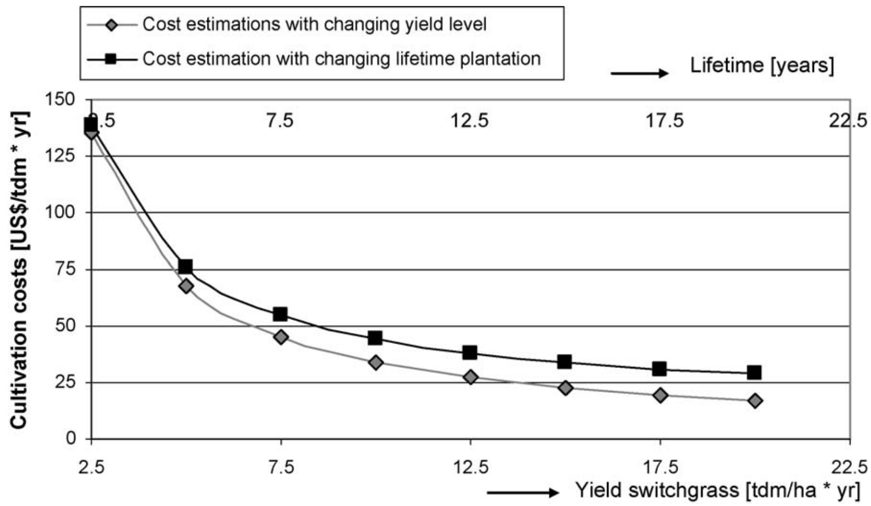

Fig. 15. Sensitivity of assumed yield and lifetime plantation on switchgrass production costs in US$/tdm/year shown for scenario (CUR-S).

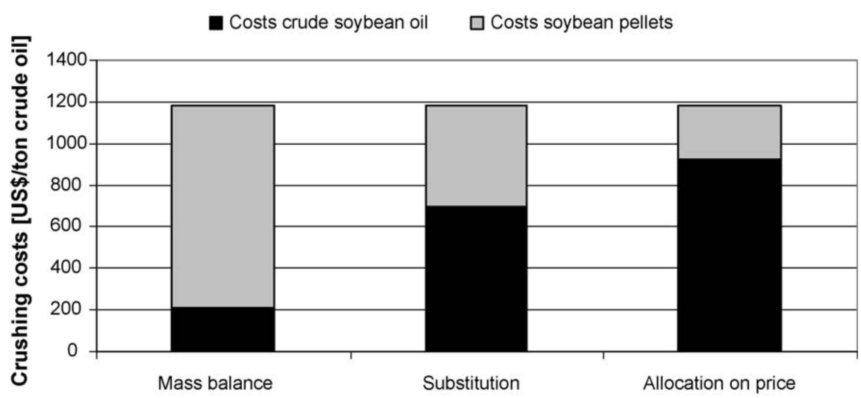

Fig. 16. Crushing costs (including grain input) for crude soybean oil in US$/t oil based on allocation by mass balance or price or based on substitution of soybean pellets by sunflower pellets.

cultivation of soybean in August 2008 range, as an example, from 245 US$/t in west Buenos Aires for limited tillage to 308 US$/t in south-east Buenos Aires for conventional farming [140]. The cost results of the future scenarios are based on assumptions following story lines that have a certain interpretation of a future world and should be interpreted this way.

Cultivation costs on the field are calculated for S and mS land for both energy crops. The yields are an output of the biomass potential assessment and based on a selected management system for all crops (see Section 3.1). Fig. 15 shows for (CUR-S) the influence of yield variation (fixed lifetime) and variation of the lifetime of the plantation (fixed yield level) on switchgrass cultivation costs. The influence of these parameters increases strongly when yield levels reduce below 7.5 tdm/ha/year or when the lifetime of the plantation is shorter than 10 years. The influence of yield levels for soybean cultivation costs shows similar results, resulting in a cost range of 440 US$/tdm to 110 US$/tdm when yield levels vary from 1 to 4 tdm/ha/year for (CUR-S).

Higher yield levels can possibly be achieved in the selected region, especially for soybeans, compared to the yield levels assumed in this study for (CUR) for several reasons. First, costs are only calculated for S and mS land in this study as no VS land is available for bioenergy production in the selected region (see Section 4.2). In case VS land would be available (without competition), yield levels would increase and cost performances improve. Second, yield levels in the assessment of the biomass for energy potential are determined per scenario for all crops based on one management system in the country. In Argentina, some parts of the country (as the humid Pampas) apply considerably better developed agricultural management systems than other areas. This diversification within the country is also visible for individual crops as the production of some crops (especially soybeans) is more intensive and developed than others.

Cost estimations of agricultural machinery and pelletisation are based on newly purchased machinery. In reality, switchgrass and soybean cultivation can make use of existing agricultural machinery available in the region and of the common practice of sharing agricultural machinery between farmers [69], which will probably reduce the calculated cultivation costs for both crops. Small pellet plants are available in La Pampa province for the production of pellets for livestock [57]. Using these plants for relatively small amounts of switchgrass bales can possibly reduce total pellet production costs as calculated in this study.

Soybean extraction results in two outputs: pellets and crude soybean oil. In this study, the crushing cost for crude soybean oil is calculated by allocation of the total crushing costs to crude soybean oil based on the mass balance of the outputs (see also Section 6.1.3). However, other options are allocation based on price or energy content or the substitution of pellets by an alternative product as applied in the LCA methodology [143]. Total crushing costs, including costs for grains, are around 200 US$/t grains (CUR-S). This is 1180 US$/t oil when no allocation or substitution is applied. Fig. 16 shows the crushing costs for crude soybean oil (including input of grains) for (CUR-S), based on different

allocation methodologies and substitution. In this example, soybean pellets are substituted by sunflower pellets, the latter having an economic value of 100 US$/t [97]. Allocation of price is based on the prices for soybean oil and pellets in Table 7 for (CUR).

The calculated costs for crude soybean oil, based on allocation of mass, are most in line with the input prices for crude soybean oil for biodiesel production given by Asal [22] and Lamers [27]. Allocation of the crushing costs for both outputs to crude soybean oil, based on substitution or prices allocation, results in considerably higher costs for crude soybean oil and consequently, in higher biodiesel production costs. This does not seem to be realistic compared to the results of other studies. Beside, national price trends of sunflower and soybean products show large fluctuations and their relative competition strongly depends on the prices in the international market [97].

7. Discussion and conclusions

In this study, the land availability for bioenergy production from soybeans and switchgrass is calculated for different scenarios on a national and provincial level in Argentina. On a national level, 18×10^6 ha (A2030) to 33×10^6 ha (CUR) of land for soybean bioenergy production becomes available. For switchgrass bioenergy production, 10×10^6 to 17×10^6 ha of land becomes available. There is a large variation in the amount of land that becomes available for biomass energy production on a provincial level, ranging for (CUR) from 0 ha (Chubut, La Rioja, Mendoza, Neuquén, Río Negro, San Juan, Santa Cruz, Tierra del Fuego) to 10×10^6 ha (Buenos Aires) for soybean bioenergy production and from 68 ha ((Tierra del Fuego) to 4×10^6 ha (Buenos Aires) for switchgrass bioenergy production.

The biomass potential on national and provincial level is calculated by multiplying the available surplus land with the productivity level of the selected energy crops. An additional allocation step is made for soybeans to calculate the amount of crude soybean oil, generated from the biomass from the whole crop. On a national level, switchgrass can reach the highest biomass potential of 243×10^6 tdm/year (4.5 EJ) in (C2030) compared to 99×10^6 tdm/year (1.9 EJ) in (A2030). Soybean (crude vegetable oil content) can reach potentials of 13.8×10^6 tdm/year (0.5 EJ) in (CUR) and of 12.6×10^6 tdm/year (0.45 EJ) in (C2030) compared to 7.1×10^6 tdm/year (0.25 EJ) in (A2030). Most bioenergy production for both crops comes from a combination of S and MS surplus land having yield ranges from 12–22 tdm/year for switchgrass and 1.5–3 tdm/year for soybeans on a *national* level with strong fluctuations/province. Overall, the available biomass potential from switchgrass is substantially higher than from soybean. The provinces Buenos Aires, Córdoba, Entre Ríos, Salta and Santa Fe have the highest biomass potential from soybeans. Buenos Aires, Córdoba, Corrientes, La Pampa and Sante Fe have the highest biomass potential from switchgrass. Possible impacts of climate change (droughts or more rain) on the biomass potential results are not taken into consideration in this study.

The selection of a suitable region for large-scale bioenergy production in Argentina was based on a defined set of criteria. These are (1) sufficient land availability for biomass for bioenergy production under different scenarios, (2) production potential for both selected energy crops in the defined region, (3) limited risk for competition between land for bioenergy production and land for food or feed and (4) proximity of logistical infrastructure. The most suitable region to cultivate energy crops, based on this set of criteria, is north-east of La Pampa province and south of Cordoba, bordering the north-west of Buenos Aires and south-east of San Luis. To analyze the economic performance, the focus in this study is on La Pampa province. The available potential for bioenergy in La Pampa ranges from 1.2×10^5 (C2015) to 1.8×10^5 (B2030) tdm/year for soybean production (based on vegetable oil content) and from 6.3×10^6 (A2030) to 18.2×10^6 (C2030) tdm/year for switchgrass production.

Switchgrass production costs in La Pampa province are 33 US$/tdm (A2015-S) to 91 US$/tdm (B2030-mS).

Cost estimates for soybean production in La Pampa province are 182 US$/tdm (CUR-S) to 501 US$/tdm (B2030-mS). Land use, machinery and fuel costs, and inputs (mainly for soybean bioenergy production) are main cost components for energy crop production. Switchgrass production has in general a better cost performance (in US$/tdm) than soybean production for bioenergy.

Based on a comparison of switchgrass cultivation costs in (CUR), being 306–339 US$/ha/year, with current costs for the production of alfalfa bales (with a cost level of 320 US$/ha and a net margin of 176 US$/ha/year) and for livestock (with a cost level of 36 US$/ha and a net margin of 17 US$/ha/year) in La Pampa province, switchgrass is expected to be competitive with livestock production and other, similar land uses in the region. Soybean production for bioenergy purposes in (CUR), being 348–440 US$/ha/year, is considered competitive with other, similar, land uses as sunflower production (183–218 US$/ha/year for direct costs only) and wheat production (427 US$/ha/year).

Pellet production costs produced in La Pampa province are 58 (CUR-S) to 143 (B2030-mS) US$/tdm for local use and 150 (CUR-S-train) to 296 US$/tdm (C2030-mS-truck) until delivery at the harbour of Rotterdam. Electricity costs for co-firing pellets in the Netherlands, replacing coal, range from 0.06 to 0.08 US$/kWh. Current cost prices for electricity from coal in the Netherlands range from 0.05 to 0.09 US$/kWh, the latter including costs for carbon capture and storage. Electricity costs for co-firing pellets in the current situation and in scenario (A2030) are close to the electricity costs from coal when costs for carbon capture and storage are excluded.

Heating costs in Argentina from switchgrass pellets, replacing natural gas, range from 0.02 (C2015-mS) to 0.04 US$/kWh (CUR2030-mS, A2030-mS and B2030-mS). The heating cost from switchgrass is competitive with the assumed heating price per scenario (ranging from 0.012 to 0.027 US$/kWh) in scenarios (B2030, C2030-mS) and close to competitive in scenario (A2030-S, C2030-mS). Based on the current low natural gas prices, switchgrass pellets for heating cannot compete at this moment with natural gas for heating in Argentina.

Biodiesel production costs in Argentina, replacing fossil diesel, range from 0.3 US$/l (CUR-S-train) to 1.0 US$/l (B2030-mS-truck). Biodiesel production costs for export to the Netherlands range from 0.5 US$/l (CUR-S-train-ROS) to 1.4 US$/l (B2030-mS-truck-ROT). Current costs for soybean biodiesel, exported to the Netherlands, can be competitive with fossil fuel costs with an oil price of 80 US$/barrel, when produced on suitable land, and with an oil price of 94 US$/barrel when produced on marginal suitable land. Local soybean biodiesel production costs are competitive with fossil fuel costs with an oil price of 55 US$/barrel, when produced on suitable land, and with an oil price of 67 US$/barrel when produced on marginal suitable land.

Key parameters for the economic performance of both bioenergy chains in La Pampa province are:

- Transport costs. Costs are reduced when favorable transport routes and transport modes are selected. It is cheaper to transport biomass inland by train than by truck.
- Cultivation costs. Allocation of biomass production on areas where a synergy in the potential and socio-economic performance can be obtained, is preferred.

- Pre-processing and conversion costs. Costs are reduced when pre-processing or conversion takes place within or near the biomass producing region, combined with an optimalization of scale and technology.
- Prices of fossil fuels and agricultural commodities. Fluctuations in soybean and crude soybean oil price in Argentina are for example strongly related to prices on the world market [18] and its cost margins may strongly decrease with declining crop prices [144]. As large areas of land in the country are dedicated to soybean production, this may create an economic risk on national level.

It must be realized that, as long as there is no market, the economy of scales is not working. If markets develop, it can be expected that costs decrease due to optimization of logistics, research and development, and technical learning. Improving the logistics of train transport in Argentina is recommended to make existing agricultural areas, further away from harbours, economically attractive for bioenergy production.

Based on our results, it can be concluded that soybean production in La Pampa province for bioenergy has a good economic performance. As large volumes of biodiesel are needed by 2010 in Argentina to comply with its Biofuels law [145], the local use of biodiesel from soybean production is recommended.

The large potential and good economic performance of the switchgrass bioenergy chain in La Pampa province, combined with an expected good environmental performance [72], makes it interesting to further develop the production of switchgrass in La Pampa province, especially on more marginal land areas.

Although the use of switchgrass pellets for local use is at this moment economically not competitive, when replacing natural gas, it might still be worthwhile to use (part of) the switchgrass pellets for local use for:

- Contributing to the target of 8% renewable energy use for electricity production in 2016 (law 26.190).
- Stimulating incentives and promoting the development of a new market for bioenergy production.
- Reducing national GHG and energy emissions when replacing GHG intensive energy sources.
- Creating a new source of revenue for farmers while diversifying the crop area [144].
- Improving access of energy in the region by using switchgrass pellets for domestic heating in places where natural gas is not available [144];
- Replacing wood used for heating that normally comes from the natural forest [52].
- Diversifying available energy sources within the region to back-up power shortages [144].

With depleting oil resources in Argentina, bioethanol production from switchgrass pellets can be an interesting alternative for heat and electricity production on the medium term. Ethanol could be produced locally for (roughly) 19 US$/$GJ_{del}$ on the short term to 10 US$/$GJ_{del}$ on the long term. Ethanol production costs further decrease from 17 US$/$GJ_{del}$ on the short term to 9 US$/$GJ_{del}$ on the long term, when switchgrass bales are directly converted to ethanol. These cost levels can be considered competitive assuming a fossil fuel production cost of 10–26 US$/GJ (with an oil price of 60–150 US$/barrel). Key pre-conditions are the availability of feedstock and national demand [27].

As switchgrass is a relatively new alternative for bioenergy production in Argentina, the development of large-scale demonstration projects, possibly integrated with other perennial grasses for livestock production, is highly recommended.

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